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SYSTEMS AUTONOMY DEMONSTRATION

THERMAL CONTROL SYSTEM FOR SPACE STATION

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PROJECT PLAN

SYSTEM AUTONOMY DEMONSTRATION OF THERMAL CONTROL SYSTEM FOR SPACE STATION

AMES RESEARCH CENTER AND JOHNSON SPACE CENTER
DECEMBER 1986

THERMAL CONTROL SYSTEM DEMONSTRATION PROJECT

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THERMAL CONTROL SYSTEM DEMONSTRATION PROJECT

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THERMAL CONTROL SYSTEM DEMONSTRATION PROJECT

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

THERMAL CONTROL SYSTEM DEMONSTRATION PROJECT

LIST OF FIGURES

THERMAL CONTROL SYSTEM DEMONSTRATION PROJECT

LIST OF TABLES

THERMAL CONTROL SYSTEM DEMONSTRATION PROJECT

CHAPTER 1

INTRODUCTION

1.1 Document Purpose

This document describes the overall plan for carrying out a Systems Autonomy Demonstration of the Thermal Control System of Space Station.

Approval of this document demonstrates acceptance of responsibilities described herein and the commitment of the necessary resources at NASA Headquarters, Ames Research Center, and Johnson Space Center to accomplish this project.

1.2 Space Station Thermal Control System

The purpose of the Thermal Control System (TCS) is to provide thermal management of all Space Station elements except individual scientific experiments and the power subsystem through heat acquisition, transportation, and rejection.

1.3 Thermal Testbed

The purpose of the Thermal Testbed is to provide a ground-based means to develop, test, evaluate, and certify elements of the Space Station Thermal Control System. The Thermal Testbed (TTB) is being constructed at Johnson Space Center.

1.4 Thermal Control System Automation Demonstration Project

This 1988 Demonstration Project will focus on automation of the Space Station Thermal Control System (TCS). A Thermal Expert System (TEXSYS) will be used to provide the automation capability. This Project is the first (1988) of a series of technology demonstrations to be carried out within NASA's Systems Autonomy Demonstration Program. Future planned technology demonstrations are described in Chapter 5, NASA Related Activities.

This TCS Project will be a joint cooperative effort between Ames Research Center and Johnson Space Center. Knowledge engineering and operator interface technologies for Systems Automation will be developed by knowledge engineers, AI researchers, and human factors researchers at ARC by relying on a close working relationship with the domain experts, knowledge and integration engineers, and mission operations personnel at JSC.

TCS Automation involves the implementation of current AI technology into the real-time dynamic environment of a complex electrical-mechanical Space Station system. It includes real-time nominal control, fault diagnosis and correction of real-time problems, design and reconfiguration advice on the Thermal testbed, and an intelligent interface to both novice and expert users.

This Project will accelerate the transfer of Systems Autonomy research technologies to user applications in a real-time operational environment, and increase user confidence in the new technologies.

CHAPTER 2

PROJECT SUMMARY

2.1 Objectives

The broad objectives of this demonstration project are to provide:

- o Technical base of in-house personnel and development tools to facilitate AI technology transfer.
- o Technology focus for Automation Research and Development in support of NASA's Space Programs.
- o Means for validation and demonstration of Automation Technology prior to transfer to Agency programs.
- o Credibility of Automation Technology within NASA.
- o Credibility of NASA AI expertise to the outside AI community.

A specific objective of this project is to provide:

- o A technology demonstration to establish automation requirements of systems operations techniques for TCS configuration monitoring, systems status, fault identification/isolation/diagnosis, and reconfiguration.

2.2 Broad Approach

This demonstration project will be a joint cooperative effort between research and operational NASA Centers: ARC and JSC. The required AI technologies will be developed and implemented by knowledge engineers, and AI and human factors researchers at ARC; while relying upon the TCS domain experts, knowledge integration engineers, and mission operations personnel residing at JSC. The demonstration will be conducted at JSC with the Thermal Control System hardware testbed.

The project approach will involve a multidisciplinary integration of knowledge engineering, man/machine interfaces, and systems architecture to enhance automation of the Space Station Thermal Control System (figure 1).

A JOINT ARC/JSC AUTOMATION TECHNOLOGY DEMONSTRATION

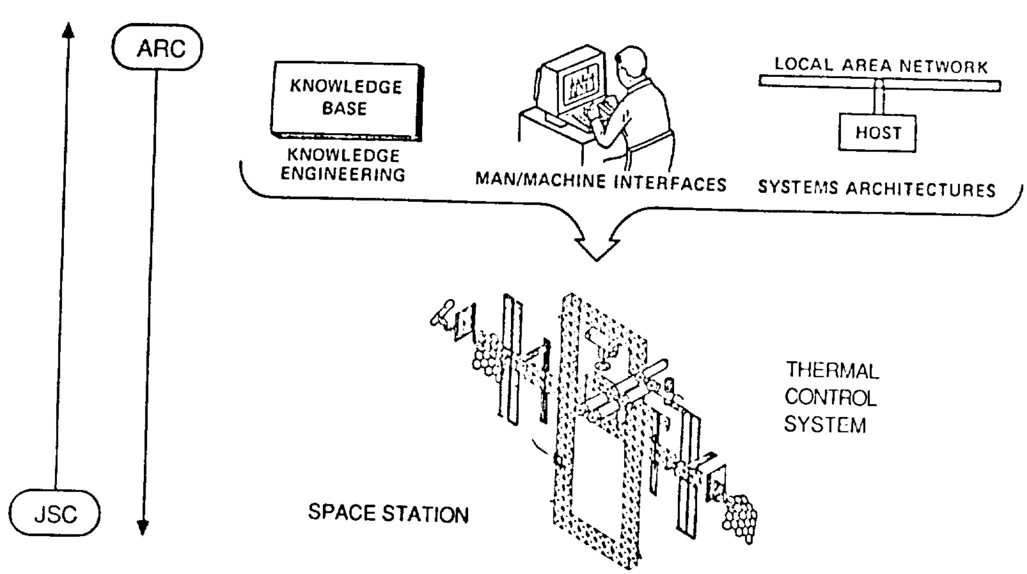

Figure 1. Project Broad Approach

The project will proceed through a phased knowledge engineering methodology consisting of: prototype knowledge base development, incremental knowledge base expansion, parallel operator interface development, and implementation in a realistic environment. Initial AI system development will be carried out in-house so as to develop a strong technical base within NASA.

The Demonstration will involve interaction with both experts and novice personnel representing mission operations, automated flight subsystems, and automated sciences. This interaction with astronauts and ground crew is a critical component of the project to insure that the human interface (man-machine) issues are properly addressed.

2.3 SADP 1988 Demonstration Selection Criteria

The following criteria were used in selecting this demonstration project. It must:

- o Provide maximum use of existing AI technologies.
- o Illustrate gains in human productivity and reductions in manpower requirements resulting from automation.
- o Have access to Domain Experts.
- o Not require unattainable personnel and equipment resources.
- o Leave a framework of people and tools which will facilitate future technology transfer.
- o Technology developed must be readily transferable to Space Station.

2.4 TCS Selection Rationale

The rationale for selecting TCS as the Demonstration Project is that it meets the above criteria and provides:

- o Guaranteed access to Domain Experts.
- o TCS slow dynamics reduce technical risks.
- o Adequate personnel and resources are available.
- o Demo schedule matches well with Thermal Testbed (TTB).
- o Environment for interface with Space Station Data Management Testbed.

2.5 TCS Demonstration Functional Features

Significant functional features of the TCS Demonstration are:

- o Fault diagnosis of 25-30 major failure modes.
- o Real-time nominal control/reconfiguration for 4-5 failure modes.
- o Trend analysis incipient failure prevention.
- o Intelligent interface to both novice and expert users.
- o Design advice on Thermal Testbed.
- o Training assistance.

2.6 Technology Thrusts

The major technology thrusts of the TCS Demonstration are:

- o Integration of knowledge-based systems into a real time environment.
- o Causal modeling of complex components and elements.
- o Combining model-based and experiential knowledge for diagnosis.
- o Trend analysis heuristic rules.
- o AI validation methodologies.

2.7 Demonstration Benefits

The major benefits of the TCS Demonstration are:

- o Promotion and establishment of strong inter-center working relationships.
- o Demonstration of Automation and Robotics technology relevance to Space Station.

2.8 TCS Automation Benefits

The major benefits of TCS Automation are:

- o Eliminates need for crew monitoring of TCS.
- o Increases crew safety through improved systems monitoring.
- o Provides TCS design assistance.
- o Simplifies novice and expert user training.

2.9 Organizational Interfaces

The Information Sciences and Human Factors Division (RC) of NASA's Office of Aeronautics and Space Technology (OAST) provides overall direction, funding, and evaluation of the Systems Autonomy Demonstration Project being managed by the Systems Autonomy Demonstration Project Office (RIS) in the Information Sciences Office (RI) at Ames Research Center.

The Thermal Control System (TCS) Demonstration Project is managed by the SADP Office (RIS) at ARC in a close working relationship with Aerospace Human Factors Division (FL) at ARC, the Crew and Thermal Systems Division (EC) at JSC, the Systems Development and Simulation Division (EF) at JSC, and the Mission Operations Directorate (DA3) at JSC.

The Space Station Thermal Testbed is being developed by the Crew and Thermal Systems Division (EC) at Johnson Space Center (JSC) from which the domain expertise is being provided. The knowledge engineering and demonstration prototype development are being done by the SADP Office (RIS) and the Artificial Intelligence Research Branch (RIA) with support from the Aerospace Human Factors Division (FL) at ARC. The Systems Development and Simulatiom Division (EF) at JSC provides support and participates with the SADP Office (RIS) at ARC in the knowledge engineering and expert system development aspects of the TCS project. The transfer from prototype demonstration to implementation demonstration will be done by ARC SADP in conjunction with the Crew and Thermal Systems Division and the Systems Development and Simulation Division, who are jointly responsible for the integration of the expert system with the

Thermal Testbed. The Mission Operations Directorate provides consultation and advice on recent trends and technology advancements in operations' automation and the application of these technologies and current mission operations' philosophy to the TCS.

2.10 Facilities

The major facility required for the TCS Demonstration is the Thermal Testbed being constructed at JSC. The Thermal Testbed includes the following subsystems: (1) Thermal System Test Articles, (pumps, radiators, evaporators, condensers, busses) and (2) a Data Acquisition and Control System (DACS).

A facility is located at ARC for development of the Thermal Expert System (TEXSYS). This facility will consist of (1) AI HW/SW development tools, and (2) a simulation HW/SW model of the Thermal Testbed for TEXSYS development and validation.

The Aerospace Human Factors Division (FL) at Ames will utilize an operator interface development facility. This facility will consist of (1) hardware and AI software for knowledge base development related to the operator interface, (2) graphics development software for rapid prototyping of interfaces, (3) hardware and software to support simulations of the TCS, and (4) hardware and software to support real-time experimentation for the evaluation of prototype interfaces.

2.11 TCS Demo Budget Summary

Table 1. TCS Demonstration Budget Summary.

	($K)	FY-86	FY-87	FY-88
Knowledge Engg.	(RIA)	100	200	
Systems Arch.	(RII)	40	70	
Operator Inter.	(FL)	0	320	
Facilies/Tools	(RIS)	0	1800	
Thermal Testbed	(EC)	30	260	
TTB Integration	(EF)	70	340	
Mission Ops.	(DA3)	0	0	
Total		240	2990	2175

2.12 TCS Demo Manpower Summary

Table 2. TCS Demonstration Manpower Summary.

	(NASA M-Yr)	FY-86	FY-87	FY-88
Knowledge Engg.	(RIA)	0.5	0.5	
Systems Arch.	(RII)	0.5	0.5	
Operator Inter.	(FL)	0.0	1.5	
Facilities/Tools	(RIS)	3.5	4.0	
Thermal Testbed	(EC)	0.5	1.0	
TTB Integration	(EF)	0.5	1.5	
Mission Ops.	(DA3)	0.0	0.5	
Total		5.5	9.5	10.0

2.13 Schedule.

The broad overall TCS Demonstration Project Schedule is shown in figure 2.

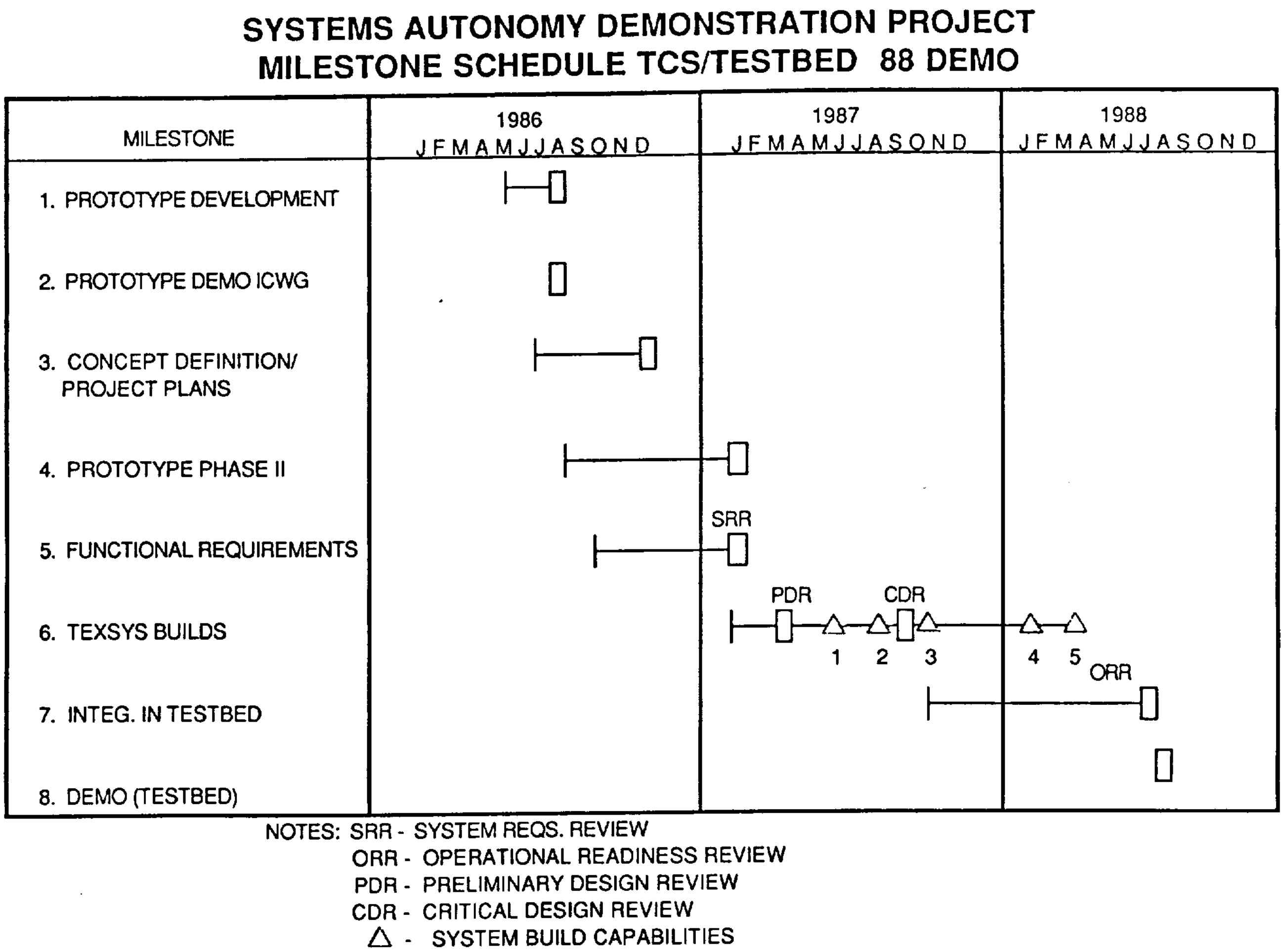

Figure 2. Broad Overall Schedule.

CHAPTER 3

SPECIFIC TCS DEMONSTRATION OBJECTIVES

Specific objectives of the TCS Demonstration Project are:

3.1 Diagnosis and Correction Advice.

The TCS can have faults in three major categories: components, control malfunctions, and sensor malfunctions. The TCS demonstration will show expert-level ability to diagnose and suggest corrective actions on approximately 25-30 common TCS faults, representing essentially all major modes of TCS failures.

3.2 Incipient Failure Prevention.

Human beings are notoriously poor at the slow and careful analysis that is needed to prevent very low frequency dynamic anomalies from escalating into problems. A potential strength of a knowledge-based systems approach to thermal managment is the use of trend analysis to detect long-term degradation and reconfiguration as required to prevent system parameters from exceeding operational limits. The demonstration will exhibit "offline" (i.e. during non-crisis times) analysis of anomalous values to make corrections to the thermal system before serious problems result.

3.3 Realtime Control and Fault Correction.

The demonstration will exhibit realtime nominal control as well as realtime correction of at least 4-5 major failure classes of the thermal system. In the context of the thermal system, realtime is on the order of seconds. The TCS expert system will analyze actual sensor data, notice and diagnose problems, and correct (or bypass) problems by sending control signals to the thermal system.

3.4 Intelligent Interface.

The demonstration will show the ability of the knowledge-based TCS expert system to explain its reasoning to users. The operator interface will allow users access to information on all stages of fault reasoning, basic physical principles underlying component and TCS system behavior, and provide guidance in making decisions involving thermal management. The interface will be a "direct manipulation" style interface, combining mouse-based pointing and menu selection as user input; and the interface will show some degree of understanding of the skill level of its user.

3.5 Training Assistance.

A beneficial side effect of knowledge-based systems is that the knowledge bases have substantial utility for future training purposes with the system. The information display capabilities will demonstrate how the knowledge-based TCS expert system can be used for purposes of crew training in the context of Space Station. Trainees will be able to examine data and simulate the effects of all known faults.

3.6 Design Assistance.

The above mentioned capability for modeling and simulation provides a substantial capacity for intelligent assistance to the design engineer using the thermal testbed. The information and display capabilities will demonstrate the ability to automatically reflect new physical realities resulting from design changes during system configuration change investigations.

3.7 Success Criteria.

Technical success criteria for the TCS Demonstration are the satisfaction of all requirements defined in the TEXSYS Systems Requirements Definition document (8.2.2). The degree to which technical success is achieved will be measured primarily by the successful completion of verification and validation tests outlined in the TEXSYS Verification and Validation Plan (8.2.3).

Programmatic success criteria, although more difficult to define than technical success criteria, are of equal importance. These criteria are the incorporation of systems autonomy technology (developed as a result of and demonstrated during the TCS Demonstration) in various Space Station subsystems and systems. This does not imply direct incorporation of TEXSYS, or any part thereof. Rather, it implies an influence on Space Station Project Offices, measured by the incorporation of autonomy requirements in subsystem requirements documents and the inclusion of automation in the design and development of those subsystems.

CHAPTER 4

RELATIONSHIP TO NASA/OAST GOALS

4.1 NASA Goals

In keeping with the mandates of the National Aeronautics and Space Act of 1958 and the National Space Strategy approved by the President and Congress in 1984, NASA has set for itself a major goal of "conducting effective and productive space applications and technology programs with contribute materially toward U.S. leadership and security".

4.2 OAST Objectives

To meet the above goal within NASA, OAST has responsibility for conducting space research and technology development to support the Nations' civil and defense space programs and overall economic growth. OAST objectives are to: (1) ensure timely provision of new concepts and advanced technologies, (2) support the development of NASA missions in space and the space activities of industry and other government agencies, (3) utilize the strengths of universities in conducting the NASA Space Research and Technology program, and (4) maintain NASA's centers in positions of strength in critical space technology areas.

4.3 Systems Autonomy Research

The Report of the National Commission on Space, published in May 1986, in its vision of the next fifty years on space strongly recommends an integration of humans and machines through automation and robotics. Specifically it is recommended that "NASA explore the limits of expert systems, and tele-presence or tele-science for remote operations, including ties to spacecraft and ground laboratories".

Congress has displayed substantial interest in accelerating the dissemination of advanced automation technology to and in U.S. industry. Space Station was selected as the high-technology program to serve as a highly visible demonstration of advanced automation, and spur dissemination of the technology to the private sector. NASA has recently initiated an Automation and Robotics Program to serve as the principal Research and Technology program contributing to Space Station automation.

Systems Autonomy research is a major contributor to Automation and Robotics technology, and is the focus of the technology being addressed in the Thermal Control System Demonstration Project.

CHAPTER 5

RELATED NASA and DOD ACTIVITIES

5.1 NASA Automation and Robotics Program

NASA has recently begun an ambitious new program in space automation and robotics. This program will result in the development and transfer of advanced automation technology to augment and make more productive a number of NASA's space progams, including Space Station.

The Automation and Robotics program is currently divided into two roughly co-equal parts. The Ames Research Center has the lead role for that portion of the program that seeks to develop Systems Autonomy. The Jet Propulsion Lab has the lead research and development role for telerobotics technology, including development and demonstration of operator interface technology for teleoperated and autonomous robots.

5.2 NASA Systems Autonomy Program.

The NASA Systems Autonomy Program technical objectives are (1) the development and integration of generic software methodologies and tools for the management and operation of complex dynamic systems, and (2) the development, test, and validation of system and subsystem planning and control technologies for automation of ground and onboard operations. Major program elements include Core Research and Technology, Technology Demonstrations, and Applications.

Core Research and Technologies are task planning and reasoning, control and execution, system architecture and integration, sensing and perception, and operator interface.

Technology Demonstrations will begin with the Space Station Thermal Control System Automation in 1988. Additional demonstrations are scheduled for 1990, 1993, and 1996. The 1990 demonstration will involve coordinated control of two subsystems through cooperating expert systems, the 1993 demonstration will involve automation and control of multiple subsystems, and the 1996 demonstration will involve distributed automation and control of multiple subsystems.

Space applications include mission operations, satellite servicing, and Space Station science payloads. Aeronautics applications include Automated Wingman, Automated Rotorcraft Nap-of-the-Earth (NOE) flight, Automated National Airspace System, and Army Aircrew/Aircraft Integration (A3I).

A major feature of this program is a strong collaborative AI research team made up of NASA, University, and Industry experts in this field.

5.3 JPL Telerobotics Program.

The Telerobotics Program at the Jet Propulsion Lab consists of basic telerobotics core research which is tightly coupled into demonstrations. Basic research is being conducted in areas of planning and reasoning, control and execution, sensing and perception, and operator interface. Initial telerobotic demonstrations are planned in 1987 (low level autonomy and teleoperation in satellite servicing) and 1990 (automatic planning and supervised execution in satellite servicing). Demonstrations are also planned in 1993 and 1996.

Major technologies to be included in the 1987 demonstration are:

a. Sensing: Visually automated acquisition, tracking and verification of CAD-referenced objects in realtime.

b. Manipulation: Cooperative two-arm handling of extended objects by force/torque compliance.

c. Control: Computer automated run-time control of manipulator arm coordination sequences and trajectories.

d. AI: Automated planning and run-time command of well defined robot servicing tasks.

e. Teleoperation: Two-arm force and torque reflecting control of robot manipulators.

f. System Architecture: Integration of sensor-driven autonomous manipulation control; run-time integration of traded autonomous and teleoperative manipulator control.

Basic core research from this program will be also utilized in demonstrations conducted under the NASA Systems Autonomy Program.

5.4 NASA Aircraft Automation Program

The program will seize upon the current opportunity for major improvements in aircraft systems through use of AI technology. AI offers the promise of higher level automation. The program objective or strategic goal is to establish a national focus for research in automation of aeronautical flight and air traffic management systems. The technology will be developed for the design of intellight flight path management systems which are goal-driven and human-error tolerant.

Goal-driven implies a higher level of interaction between the pilot and his aircraft systems than currently available. Communications will be by intent rather than by having to select specific autopilot modes or insert specific waypoints by latitude/longitude coordinates. In helicopter automated NOE flight the vision might be one of the "horseman who controls the horse by simple commands" and not high bandwidth/precise path control.

The program potential payoff is in the form of improved mission effectiveness, elimination of operationally caused accidents, and reduced crew complement and training costs. These opportunities are available for high performance aircraft, rotorcraft, and civil transports. Recognized mission requirements in these three vehicle classes provide the research focus. The primary emphasis initially will be in the area of automated helicopter NOE flight which is being worked at NASA Ames Research Center in conjunction with the Army Aeroflightdynamics Directorate.

5.5 Army-NASA Aircrew/Aircraft Integration Program

This program is an Army-NASA exploratory development program with the purpose of developing a rational predictive methodology for helicopter cockpit system design, including mission requirements and training system implications, that integrates human factors engineering with other vehicle/design disciplines at an early state in the development process. The program will produce a prototype Human Factors/Computer Aided Engineering workstation suite for use by design professionals. This interactive environment will include computational and expert systems for the analysis and estimation of the impact of cockpit design and mission specification on system performance by considering the performance consequences from the human component of the system. The technical approach is motivated by the high cost of training systems, including simulators, and the loss of mission effectiveness and possible loss of lives due to ill-conceived man-machine design. The methodology developed to achieve goals of this program might be generalized as a paradigm for the development and planning of a variety of complex human operated systems.

The program is jointly managed and executed by the Aeroflightdynamics Directorate of the US Army Aviation Research and Technology Activity (ARTA) and the NASA Ames Research Center Aerospace Human Factors Research Division.

5.6 DARPA Information Science Technology Office.

The Defense Advance Research Projects Agency (DARPA) has recently combined its basic AI research and technology demonstration projects within a single office called Information Science Technology Office (ISTO), under the direction of Professor Saul Amarel. ISTO and its predecessor, Information Processing Techniques Office (IPTO), are the largest single source of funding for basic and applied AI research in the world. ISTO funds continuing AI research efforts at universities such as Stanford, Carnegie-Mellon, and MIT (typically at $1M/yr). Funded projects include the areas of knowledge representation, knowledge acquisition, and advanced inference methods such as the blackboard system, and machine learning.

In addition, a major effort analogous to Systems Autonomy, called Strategic Computing, was started approximately two years ago. The purpose of Strategic Computing is to both build and demonstrate the appliced AI technology base necessary for military users in the next several decades. Seven applied research programs are being funded at places such as IntelliCorp., Teknowledge, GE, Stanford University, and University of Massachusetts in areas of next-generation AI tool development and advanced hardware and software architectures for AI systems. Three major demonstrations, Pilot's Associate, Autonomous Land Vehicle, and Air-Land Battle Management are currently underway in multi-company teams.

Through various efforts, both formal and informal, demonstrations presented as part of the Systems Autonomy program will utilize and leverage upon DARPA developed technolgy. The ARC Information Sciences Office is currently finalizing a working arrangement with the DARPA ISTO.

CHAPTER 6

SYSTEM CONCEPT

The major purpose of the TCS Demonstration Project is to demonstrate the ability to successfully implement current AI technology into a real-time operational environment of Space Station, and to demonstrate benefits of Systems Autonomy in Space Station. By accomplishing this purpose, the TCS Demonstration Project will accelerate transfer of Systems Autonomy research technologies to user applications, and will increase user confidence and acceptance of these new technologies.

The general technical plan is a multidisciplinary integration of knowledge-based engineering, systems architectures, and man-machine interface to achieve automation of the Space Station TCS. Applications of AI technologies developed at ARC will strongly rely upon the thermal systems domain expertise of the Crew and Thermal Systems Division, the knowledge engineering and integration skills of the Systems Development and Simulation Division, and the operational experience of the Mission Operations Directorate at JSC.

6.1 General Thermal System Requirements.

The Thermal Control System provides thermal management of most space station elements through heat acquisition, transportation, and rejection. A schematic of the baseline two-phase Space Station TCS is shown in figure 3. General system requirements are:

a. Narrow-band temperature control among all service areas.
b. Long-distance transport of waste heat.
c. Multiyear service realiability.
d. Reconfigurable heat source operation.
e. On-orbit growth capability to satisfy Space Station requirements.

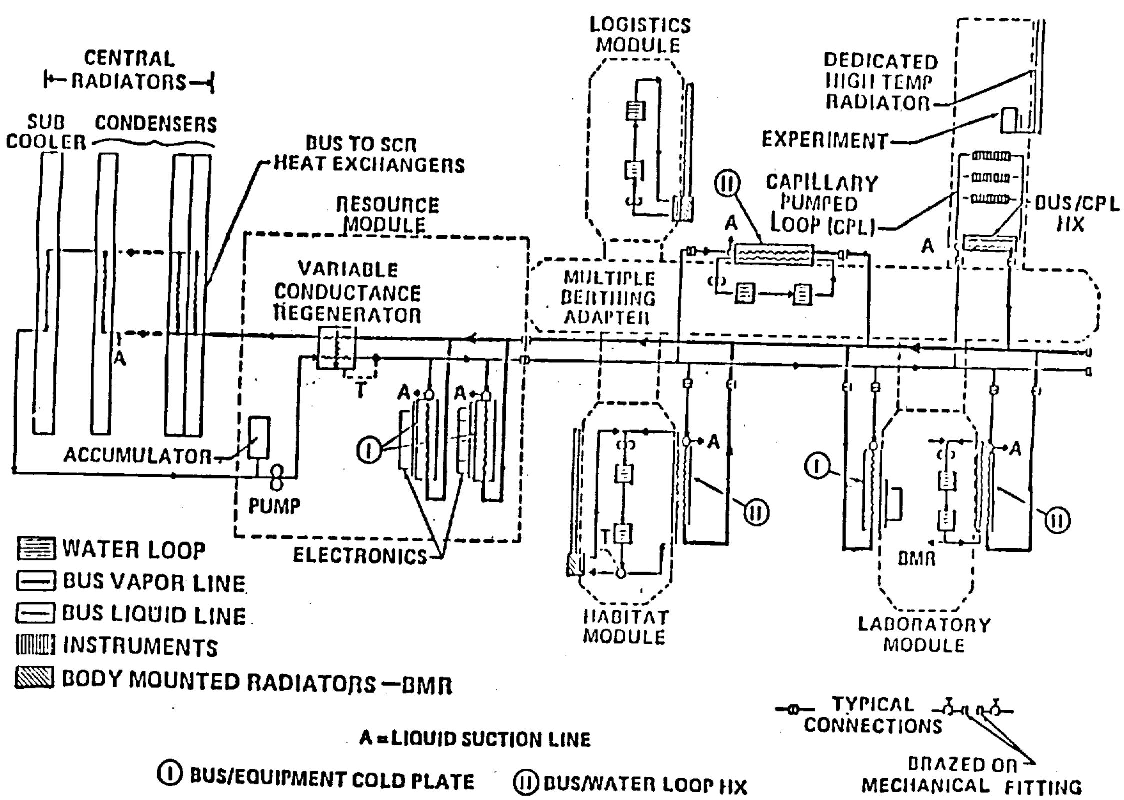

Figure 3. Schematic of Space Station Thermal Management.

6.2 General TTB Data Acqusition and Control (DACS) Functions.

The TTB Data Acquisition and Control Functional Breakdown is shown in figure 4.

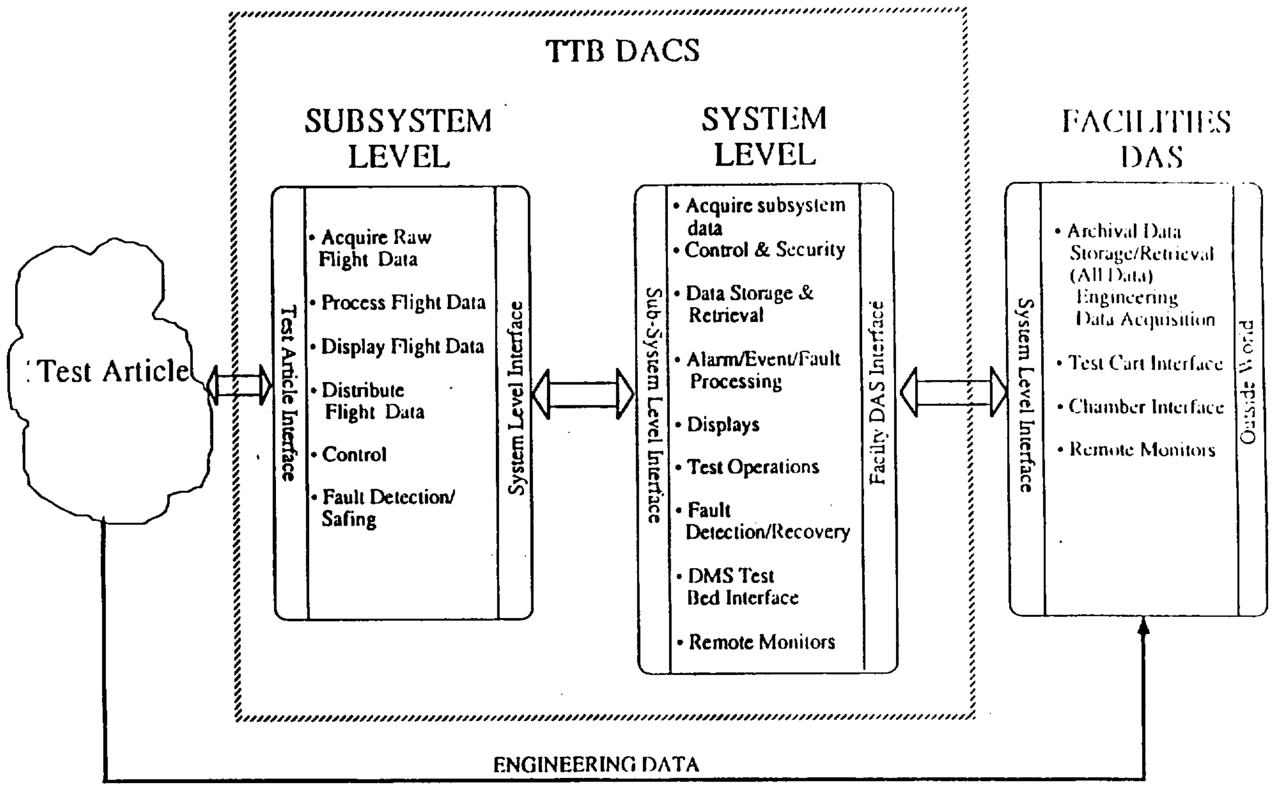

Figure 4. TTB DACS Functional Breakdown.

6.3 General Thermal Control Expert System Functions.

The Thermal Control Expert System (TEXSYS) knowledge-based functions within the TCS are:

a. Nominal real-time control.
b. Fault detection.
c. Fault isolation.
d. Fault correction advice and reconfiguration.
e. Design and configuration optimization.
f. Training.

6.4 TEXSYS Conceptual Configuration with the Thermal Testbed DACS.

The conceptual configuration of TEXSYS within the Thermal Testbed is shown in figure 5.

Individual test articles are directly connected to control computers (microVaxes) which then connect to an Ethernet. A DACS computer (a larger microVax II) acts as a system controller, central data router and command queuer for the testbed. TEXSYS, initially running on a specialized LISP machine will be connected via standard DECNet protocols to the Ethernet. It may receive data from the DACS system and pass commands to the DACS system. If this routing strategy is not sufficiently fast or powerful, data will be received from and commands passed directly to the test article controllers.

Another possibility for increasing speed would be the use of a conventional computer as a front-end processor (FEP) along with a Lisp machine. Such an arrangement could be useful if the major speed bottleneck turns out to be in handling the raw data from DACS. The FEP could handle pre-processing tasks to reduce the raw data to a compressed amount of information that can be handled by the expert system. It might be possible that the DACS itself could provide this data reduction. Further investigation of this area will be necessary.

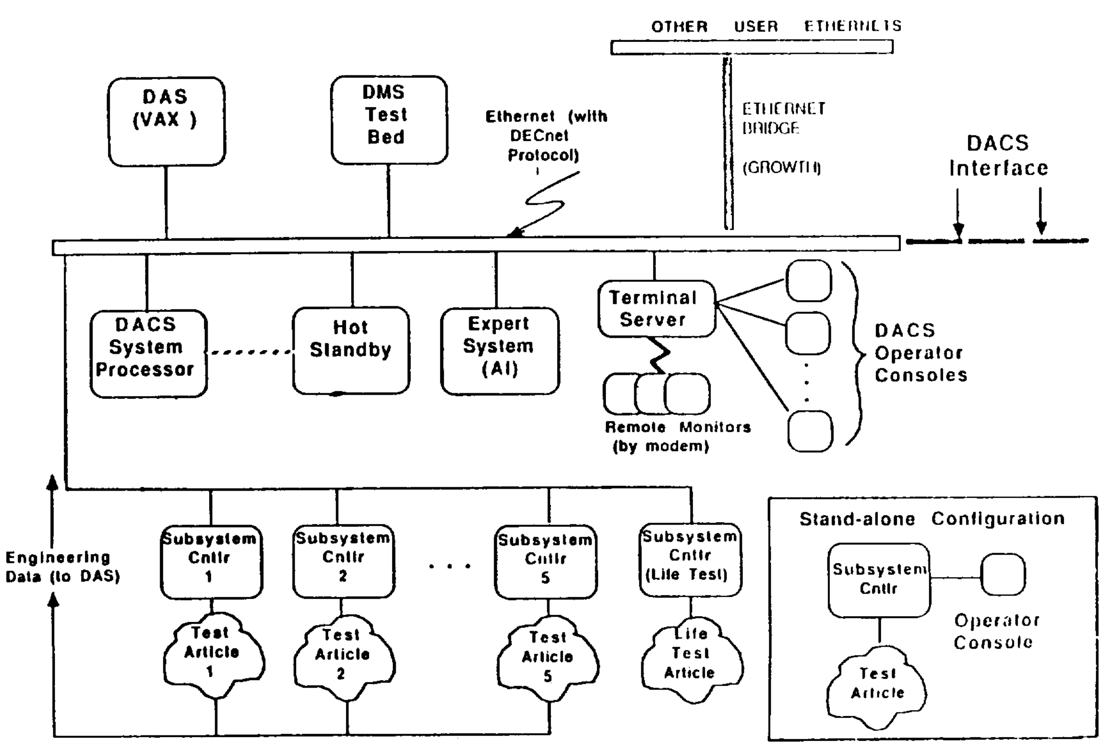

Figure 5. TEXSYS Conceptual Configuration in TCS Testbed.

6.5 TEXSYS System Development Environment.

The initial version of TEXSYS will make use of the KEE knowledge base building tool (from IntelliCorp, Inc.) and the ZetaLisp development environment (from Symbolics, Inc.) running on one of the Symbolics family of Lisp workstation computers. Some development work may involve use of Texas Instruments Explorer Lisp workstations which are compatible with the Symbolics equipment, but somewhat less expensive and slower. User interface design will make use of some combination of the standard Symbolics bitmap display and an attached color graphics, such as possibly a Sun workstation. The Symbolics ZetaLisp environment provides simple mechanisms to directly call the FORTRAN subroutines that are used to send the proper information requests and reconfiguration commands out to the ethernet.

6.6 TEXSYS Knowledge Base.

The TEXSYS knowledge base will rely to a large degree on both experiential heuristic rules and causal or model-based reasoning. The initial TEXSYS concept will use a frame-based, hierarcnical, object-oriented representation of knowledge. Frame-based means that each structural component of a thermal system, or each class of components, is represented by a collection of quantitative and qualitative facts about the component. Hierarchial means that each entity is not represented as a separate item, but as a tree of structures. Object-oriented means that both factual and procedural knowledge are accessed through the same mechanisms. Figure 6 below shows examples of how the knowledge base is subdivided into thermal rules, systems, and component models.

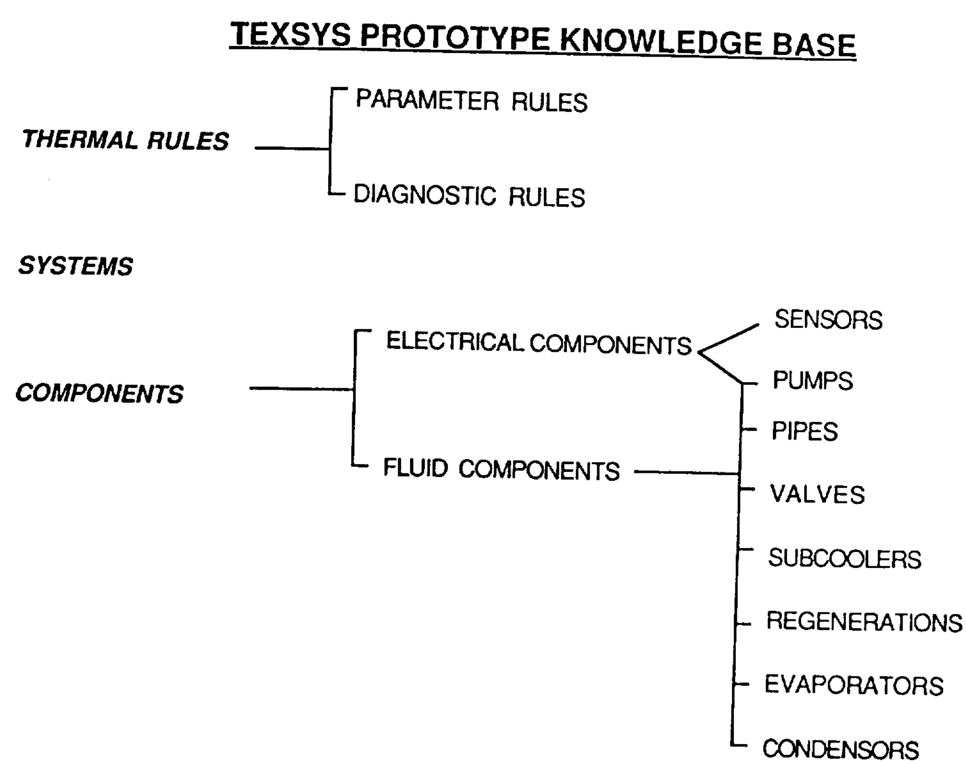

Figure 6. TEXSYS Knowledge Base Example.

6.7 TEXSYS Modeling and Simulation.

The basis of all modeling and simulation in TEXSYS is the structural and functional knowledge base. Part of the knowledge base construction task is to include pointers to relevant, existing mathematical models, to first principles of thermal engineering, and to heuristics for parameter propagation, for all components and subsystems involved in thermal management. Simulation in any of those cases proceeds in a straight-forward, object-oriented manner. This means that a "simulate yourself" message gets passed to the relevant structure that is to be modeled and procedural knowledge of the appropriate form is activated. For math models, this is normally a call to a Fortran subroutine; however, for qualitative causal models, software tools convert laws of thermal sciences into actions; and for heuristic propagation of parameters, forward chaining is normally satisfactory.

The most difficult technical task will be the third step (the first two being description of the structural and functional knowledge, and developing inference methods to use that knowledge). This difficult third task is selection of which of the three types of models (heuristic, qualitative, or quantitative) to use for any simulation, and the appropriate combination of information from different models. The selection itself will almost surely be heuristic, based upon expert knowledge of the relevance and trustworthiness of the various types of models in different situations. Combinations of models, especially when we are attempting to combine quantitative and qualitative knowledge, will be a significant research task. Most of the work will be experimental, testing various models in many different situations and determining the relevant speed/accuracy/cost tradeoffs that apply.

CHAPTER 7

TECHNICAL PLAN

The general technical plan is a multidisciplinary integration of knowledge-based engineering, systems architectures, and man-machine interface to achieve automation of the Space Station TCS. The implementation ofAI technologies developed at ARC will rely upon thermal system domain expertise of the Crew and Thermal Systems Division, the knowledge engineering and integration skills of the Systems Development and Simulation Division, and the Mission Operations Directorate at JSC.

This chapter describes the technical objectives, justification, and approach for accomplishing the TCS Demonstration broad objectives.

7.1 <u>Diagnosis and Correction Advice</u>.

a. Objective. Demonstrate expert-level ability to diagnose and suggest corrective actions on approximately 25-30 common TCS faults.

b. Justification. Fault detection and diagnosis accomplished autonomously will significantly reduce the burden on the crew of monitoring Space Station subsystems.

c. Technical Approach. There are two basic mechanisms of use to both humans and machines for diagnosing and correcting problems: experiential heuristics and formal models based upon first principles of domain. The first generation of successful "expert" systems were based entirely on the first mechanism. They drew their expertise usually from many domain-specific rules which provided intelligent guesses as to what flaws could have caused certain symptoms and how to correct the flaws. But skilled humans do not always rely on heuristics alone. Sometimes they delve more deeply into the technical aspects of a problem, trying to understand causal relationships based upon the physical, chemical, or biological laws of the domain.

The importance of this deeper form of reasoning has led to current work on causal or model-based reasoning in knowledge-based systems. It involves building complete structural and functional models of the objects and their interactions in the domain. In the case of the Thermal Management System, this means description of all of the relevant properties of the valves, pumps, condensers, etc. that the systems consists of, along with a complete description of the functional interrelationship among the components.

The starting approach to be used on TEXSYS is a framed-based, hierarchical, object-oriented representation of knowledge. Frame-based means that each structural component of a thermal system, or each class of components, is represented as a collection of quantitative and qualitative facts about the component. For example, associated with a given valve might be properties such as cost, time to close, and maximum flow rate through the valve. Hierarchical means that each entity is not represented as a separate item, but as a tree of structures, each inheriting properties and property values from more general classes of structures in the hierarchy. For example, the Boeing Radiator for the Thermal System is a "child" of the generic concept "Radiators" which is itself a "child" of the even more general class of items "Mechanical Components". Object-oriented means that both factual and procedural knowledge are accessed through the same mechanisms. For example, instructions on how to remotely speed up a pump in the Thermal System are (conceptually) stored the same way any factual characteristics of that pump are stored.

Besides the description of all of the domain objects, two other forms of knowledge are important to TEXSYS. The first is the collection of experiential heuristics that are used to do "shallow" diagnosis as described above. These are stored as English-like (or more properly "thermal engineer English-like") rules associated with specific types of components in the knowledge base. The second form of knowledge is composed of the first principles of thermal engineering which describe functional interrelationships among objects in the domain. These are represented in a variety of manners, ranging from formal mathematical relationships, when known, to qualitative value propagation rules when only order-of-magnitude and directionality values are known.

The most important, and most arduous, task in all of this effort is called knowledge acquisition: the process of taking information known to thermal engineers and storing it within a knowledge base. This task is greatly aided by using one of the commercially available knowledge base building tools (a time saving of at least an order-of-magnitude over describing the information in a "raw" programming language like LISP), but still requires the active intervention of human knowledge engineers.

A second task, normally requiring less time than knowledge acquisition, is determining ways to effectively utilize the expert knowledge in TEXSYS. Experiential heuristics can be used for diagnosis and correction advice by straightforward inference methods such as forward chaining from data or backward chaining from potential problems. (Automatic forward and backward chaining mechanisms are very simple and are built into all of the commercially available tools). Mathematical and qualitative "deep" models are used for diagnosis by constrained simulation of overall effects of potential flaws (i.e. narrow down the search for problems and then use the formal/informal models to determine which of the potential problems could have caused the actual flaw). An important research question is how to best combine these two forms of reasoning (experiential and causal modeling) in a synergistic manner. The initial technical approach will view the heuristic diagnosis as likely to be fast and effective when identical or similar problems have already been described to TEXSYS; and model-based diagnosis will be needed when unpredicted problems arise or when the Thermal System configuration has changed enough to obviate prior experience. A related issue involves determination of levels of abstraction for qualitative models. Unresolved issues are what these levels of abstraction should be and how they should interact.

It is important to note that the development of the knowledge base task (which in most prior significant knowledge-based system projects has occupied by far the bulk of the system-building time), involves little computer programming in the traditional sense. The path is one of incremental refinements of individual components of the knowledge base as well as overall knowledge base organization. A modern knowledge base building environment (the TEXSYS prototype utilized KEE) will be used which supplies much of the functionality described above. Most of the time will be spent by a team of knowledge engineers and domain experts in elucidating and experimenting with thermal knowledge, both generally and specifically related to the test articles of the Thermal Testbed. Some customization will be needed, particularly in areas of model-based diagnosis and simulation. The resulting knowledge base, combined with mostly off-the-shelf and straightforward reasoning or inference methods, will be the heart of the TEXSYS system.

7.2 Incipient Failure Prevention.

a. Objective. Demonstrate use of automated trend analysis to detect long-term degradation and to reconfigure as required to prevent system parameters from exceeding operational limits and creating "hard" failures.

b. Justification. A potential strength of knowledge-based systems approach to thermal management is use of trend analysis to detect long-term degradation and to reconfigure as required to prevent system parameters from exceeding operational limits. Because human beings are poor at the long term analysis that is needed to prevent very low frequency dynamic anomolies from escalating into larger problems, this is a very good application area for knowledge-based systems.

c. Technical Approach. From a technical point of view, this function can be viewed as a separable, offline analytical task. The DACS in the Thermal Testbed will maintain a database of sensor information that can be perused "at leisure" by TEXSYS when acute failure is not a problem. A system is envisioned along the lines of the RX project at Stanford which does long-term data analysis of arthritis patient records. The RX system employs heuristic knowledge both about the specific domain and about statistical analysis.

The first step is to find statistically meaningful trends in sensor data; this involves knowledge about the definition of "meaningful" both from the thermal engineering and the statistical point of view. After a trend has been found, analysis can proceed in one of two ways. The most straightforward form of analysis is to treat the trend in precisely the same manner as any "failure". A second method will involve the use of special long-term heuristics that relate to gradual changes in the properties of components; an example might be eventual degradation of radiator surfaces by micrometeorite bombardment.

The technical difficulty of this task lies in the relative lack (compared to acute failure diagnosis and correction) of good experiential heuristics. Collecting useful knowledge from TEXSYS domain experts will be more difficult than in the acute failure cases. In theory, all of the data needed will be available in the DACS database, the statistics are reasonably well understood, and the structural and functional model of the thermal components should serve well. However, the relative lack of documented case studies and human expertise in this area will make progress dependent upon research investigations as well as engineering endeavors.

7.3 Realtime Control and Fault Correction.

a. Objective. Demonstrate realtime nominal system control, and realtime correction of at least 4-5 major failure modes of the Thermal Control System.

b. Justification. Realtime thermal control is a major and crucial challenge to success of the Demonstration if it is to be viewed as the operational precursor to a functional Space Station subsystem.

c. Technical Approach. The current view of control in the Thermal Testbed is a good starting point for this objective. Individual thermal subsystems (most commonly complete thermal busses) are connected to a subsystem control computer which acts as a data and control device. The individual control computers are connected to a standard Ethernet running the Decnet protocol. Also connected to the ethernet will be a Data Acquisition and Control System (DACS) MicroVax II computer which will process data on the net, note pre-specified alarm conditions on particular sensor values, and act as a queueing device for high level control signals back to the Thermal Testbed articles. The DACS will be operational by July 1987.

Initially, the TCS expert system will be integrated into the TCS Testbed by simply connecting it to the Ethernet. Data packets may be received by TEXSYS from the DACs and command packets sent back. Initial experiments will determine if this mechanism if sufficiently fast for realtime operation. If not, the next step is to request information from and provide commands to the subsystem controllers directly.

Finally, it could occur that the DACS hardware environment is fast enough, but the knowledge-based system is processing information too slowly for realtime operation. In that case, portions of the system may need to be "downloaded" to a faster runtime workstation system connected to the ethernet.

7.4 Intelligent Interface.

a. Objective. The demonstation will show the ability of the knowlege-based TCS expert system to explain its reasoning to users. The operator interface will allow users access to information on all stages of fault reasoning, basic physical principles underlying component and TCS system behavior, and provide guidance in making decisions involving thermal management. The interface will be a "direct manipulation" style interface, combining mouse-based pointing and menu selection as user input.

b. Justification. The primary roles for the human operator in the fault diagnosis of the TCS will be to validate the expert system's diagnosis and action, and to plan or reschedule as needed to accomodate the failure. The operator interface will be the principle means of accessing the TCS system's knowledge base in support of these activities.

c. Technical Approach. One of the main goals of the TCS expert system is to free users, especially astronauts, from routine monitoring and diagnostic tasks related to the TCS. Users of the TCS expert system will be actively involved in fault diagnosis only for the most difficult faults or when automatic fault diagnosis fails. They will have little routine dialog with the system. However, operators will be expected to intercede after the fault has been detected, to validate the expert system diagnosis; and plan and develop an appropriate contingency plan. The knowledge base of the expert system, with some augmentation, could be used to aid these activities. Experience with automation in aircraft has shown how difficult it is to keep aircrews aware of important flight information when much of it is processed automatically by equipment whose operation is poorly understood by crewmembers.

The operator interface for the TCS seeks to overcome these problems by providing operators of the TCS with multiple ways of examining system diagnoses. Three key areas will be targeted. First, users will be able to examine the expert systems reasoning and information. Two levels of explanation will be available, a rule-trace and a causal explanation. The rule-trace will permit the operator to check system logic and insure that all relevant sensor data was considered. The causal explanation will deal with the logic of the rules, detailing the relationship between symptoms and faults. The operator will also be able to examine specific fault hypotheses to see supporting and contradictory evidence. A logic trace will also be available to look at the expert system's reasoning at selected points in the process. Time-history data of TMS parameters will be saved should operators need to examine raw data.

Second, should examination of the fault logic be insufficient, or should the operators need more systems-level information to aid decision making, they will be able to examine the basic physics of the TCS, and have access to engineering data on both components and overall system performance. The data can be presented either as graphs or as pictures, where components are represented iconically. The displays will be interactive, so that users can alter values and see the resulting outputs. Third, operators will be able to simulate the effects of some given state. This would be useful in extrapolating the consequences of some known fault to mission performance, investigating the symptoms associated with a fault, or determining the likely useful lifetime of a marginal component and its effects on TCS performance. This process might be implemented via forward chaining on the TCS knowledge base. A similar capability using backward chaining could be used to examine the likelihood of some undesirable outcome.

To facilitate use by less-trained operators the interface will use mouse-based pointing combined with menu selection as the primary means of input. No command line input other than that supported by the underlying operating system is planned. The direct manipulation style of interface reduces the memory demands on operators and offers a natural, easy to learn method of selecting and displaying information. Explanations, and information display in general, will make extensive use of combined text and graphics. Object oriented programming will be used to facilitate the separate examination of components and their properties.

7.5 Training Assistance.

a. Objective. An offline inherent capacity of knowledge-based systems is that the knowledge bases have substantial utility for future training purposes with the system. The information display capabilities will demonstrate how the knowledge-based TCS expert system can be used for purposes of crew training in the context of Space Station. Trainees will be able to examine data and simulate the effects of all known faults.

b. Justification. The TCS expert system is being designed to explore the applications of AI to Space Station systems. The system will be used by trained, but non-expert personnel, and will not be routinely used. It is important to incorporate features in the operator interface that can be used in initial training and as a refresher for in-flight operators.

c. Technical Approach. The knowledge base of the TCS expert system will contain rules and information that would be useful in training and updating users. In particular, the expert system incorporates basic physical principles and supports various levels of simulation based on models of the TCS. This simulation capability can be exploited to form an interactive instructional aid for operators.

Two forms of interactive instruction will be available. First, it will be possible to learn the basic physics of heat transfer involved with the TCS and examine principles of operation of any system component of selected set of components. Operators will be able to select desired sub-sets of components, connect them in various ways, and examine their behavior in a wide variety of contexts. Second, operators will be able to simulate the effects of selected faults, examine the effects on the TCS system and observe the consequences for mission performance.

The interface will be a direct manipulation interface as described in section 7.4c.

7.6 Design Assistance.

a. Objective. The above mentioned capability for modeling and simulation provides a substantial capacity for offline intelligent assistance to the design engineer using the thermal testbed. The information and display capabilities will demonstrate the ability to automatically reflect new physical realities resulting from design changes during system configuration investigations.

b. Justification. The major overall goal of the TCS TEXSYS Demonstration is to provide technology for autonomous, intelligent control of a major Space Station system. However, within the Thermal Testbed design environment, there is a substantial potential for significant time and cost savings in parallel with achievement of the overall goal. This is because the knowledge base of the TCS expert system will contain information and reasoning capabilities that could be used to aid thermal engineers in evaluating system components and configurations during thermal system design phases.

c. Technical Approach. In a sense, design assistance comes as a "free" spinoff from other technical efforts on TEXSYS. Since the knowledge base contains close to complete structural and functional information about all Thermal Testbed components and configurations, it will serve as an easily accessible repository of useful facts and heuristics for the thermal engineers--an intelligent encyclopedia. The simulation and modeling capabilities described earlier, combined with a reasonably intelligent interface (discussed above), allow the thermal engineer to easily carry out "tradeoff experiments" on the system without incurring the expenses of actual tests in the Thermal Vacuum Chamber.

For example, if the thermal engineer wishes to determine what changes in system behavior would result from substituting one type of radiator design for another, TEXSYS will provide a rapid method for accomplishing this. The thermal engineer would display the system schematic and touch the existing radiator with a mouse-driven cursor, touch the new radiator frame in the knowledge base with the cursor, and command a "substitute" through a pop-up menu. Given the object-oriented nature of TEXSYS, the substitution automatically takes care of all propagation of structural and functional parameters that require changing due to the new system radiator. This could be carried further by providing a report to the thermal engineer of all significant (by some easily modifiable standard of significance) effects of the change.

Achieving this objective comes mainly as a subsidiary benefit of other TEXSYS technical efforts. Additional work is mainly required only to make sure that any specialized needs or desires of the thermal engineers are considered during the course of TEXSYS development. It is anticipated that the major technical effort in this area will be on the interface design, not on extra demands on the knowledge base construction or reasoning developments. As discussed in sections 7.4 and 7.5, the operator interface will allow access to information and simulation capabilities of the expert system to enable operators to explore the behavior or the system under a wide variety of conditions.

7.7 Core AI Research Traceability to TCS Objectives.

The TCS Demonstration Project provides a strong "pull" to basic core AI research. The Core AI research and technology consists of elements in broad categories of Planning and Reasoning, Control and Execution, and Systems Architecture. Demonstrations will have the following general characteristics:

1988 Demonstration:	Expert control of single subsystem.
1990 Demonstration:	Expert control of two subsystems.
1993 Demonstration:	Hierarchical control of multiple subsystems.
1996 Demonstration:	Distributed control of multiple subsystems.

Traceability into SADP of the basic AI research being conducted at ARC is shown in table 3.

Table 3. CORE R&T TRACEABILITY TO DEMONSTRATIONS

Core Research & Technology	Demonstrations 88	90	93	96
PLANNING AND REASONING				
Causal Modeling and Simulation	XX	XX	XX	XX
Explanation and Interface Technology	XX	XX	XX	XX
Validation Methodologies	XX	XX	XX	XX
Reasoning Under Uncertainty	X	X	XX	XX
Next Generation Tools		X	XX	XX
Acquisition of Design Knowledge		X	XX	XX
Constructing Large Knowledge Bases		X	XX	XX
Advanced Methods for Plan Construction/Monitoring			X	XX
Machine Learning			X	XX
CONTROL AND EXECUTION				
Hierarchical Control of Multiple Systems		X	XX	XX
Distributed Cooperation of Multiple Systems				XX
SYSTEMS ARCHITECTURE				
Spaceborne Symbolic Processor		X	XX	XX

7.8 Researach Contracts/University Grants.

Research contracts and University Grants potentially contributing to the SADP include those shown below in table 4.

Table 4. RESEARCH STUDIES APPLICABLE TO SADP.

Institution	Grantee	Activity
PLANNING AND REASONING		
SRI		Proc-based Knowledge Representation
DeAnza	Frederick	Knowledge Engineering Support
U. Maryland	Larsen	Distributed Large Data Bases
Stanford	Feigenbaum	Advanced AI Architectures
UC Berkeley	Zadeh	Fuzzy Logic
RIACS	Cheeseman	Probabilistic Knowledge
Stanford	Buchanan	Spatial Reasoning
Stanford	Flynn	Prolog Machines
RIACS	Johnson	Data Network Concepts
Michigan	Volz	Multi-Sensor Integration
CONTROL AND EXECUTION		
Stanford	Cannon	Intelligent Mobile Robots
OPERATOR INTERFACE		
MIT	Sheridan	Man-Machine Interface

CHAPTER 8

DEVELOPMENT PLAN

8.1 General Approach.

In any knowledge engineering project the work proceeds by incremental refinement of a relatively simple system, adding knowledge and consequently ability to perform better; and carrying out research in how to better combine types of knowledge and reasoning methodologies.

As one of the largest knowledge engineering projects yet attempted, this demonstration will use the above described approach, and will also proceed along traditional project development methods: definition of the problem, specification of system requirements, definition of system specifications, development, validation, integration, checkout, and demonstration. This approach is necessary due to the scope of work and the numbers of people and organizations involved. The intent of this approach is to provide successful accomplishment of the TCS Demonstration within the pre-established schedule and budget constraints.

8.2 Specific Approach.

The development and demonstration of the TEXSYS system will be accomplished through six major stages, most of which are separated by major project reviews. These stages include:

a. Prototype Development Stage.
b. Requirements Definition Stage.
c. System Specification Stage.
d. Initial System Development Stage.
e. Final System Development Stage.
f. Demonstration Stage.

This section identifies the activities to be accomplished in each of these stages, and the review activities that will assure that the project is ready to advance to the next stage.

The TCS Demonstration development approach will be re-examined at each major review and modified as technical, schedule, and budget status suggest appropriate. Changes in the development approach will be documented in the Project Management Report.

8.2.1 Prototype Development Stage.

As a first step in the problem definition and incremental engineering process, a small but significant prototype was constructed in June and July, 1986. The objectives of the prototype development were:

a. To learn significantly more, directly from an expert, about the thermal testbed environment and about thermal engineering, especially as related to two-phase thermal systems on Space Station.

b. To provide knowledge engineering training for ARC RI SADP personnel in a practical, problem oriented environment.

c. To build a working prototype system that would serve as a starting point for future work.

An analysis was made of probable TEXSYS functional and performance requirements, available hardware, software, expert system building tools, and training and engineering support. Based on this analysis, a selection was made as to the hardware and software to be used for the prototype development, and for the TEXSYS demonstration.

The work was done as a cooperative apprenticeship program under contract to a knowledge-engineering company, which provided several highly experienced knowledge engineers to assist in prototype development. All of the prototype demonstration objectives were accomplished successfully, and the prototype system was demonstrated to the SADP Inter-Center Working Group in July 1986.

Following this demonstration, more engineering analysis and project planning has been accomplished to formalize the technical approach and the organizational agreements. This work is documented in this TCS Demonstration Project Plan.

8.2.2 System Requirements Definition Stage.

The next step in the development and demonstration of the TEXSYS system is the formal and specific definition of requirements. Particular care will be paid to interfaces to the operator and to the TCS Testbed computers, to real-time data collection and TEXSYS performance requirements, and to the architectural structure of the TEXSYS knowledge base. These will be documented in the TEXSYS System Requirements Definition and will be reviewed at the TEXSYS System Requirements Review. Included in the requirements definition will be a description of the various simulations required to verify the expert system. These simulations may include, but are not limited to, static scenario generators, dynamic (open-loop and closed-loop) mathematical simulations, and qualitative models. The SADP Safety Plan and the SADP Documentation Plan will also be reviewed at the SRR. The development hardware and software will be defined during this stage.

8.2.3 System Specification Stage.

Following the successful accomplishment of the SRR, work will shift to the generation of a system design, including design of the knowledge base architecture, specific interfaces with necessary utilities, other systems, and the human operator or user of the TEXSYS, and the structure and format of data to be used as real-time input and output. This will be documented in the TEXSYS System Design Specification which will also specify the delivery hardware and software.

Several other SADP and TCS Demonstration control documents will also be developed during this phase of the demonstration activities. These include the following:

a. TEXSYS Hazards Analysis. This analysis will identify potentially hazardous failure modes. This information will be used in the development of the design of the TEXSYS to eliminate, to the maximum degree feasible, all failure modes that pose hazards to personnel; and to eliminate or minimize failure modes that pose hazards to equipment, the TCS Testbed, or the TCS Demonstration.

b. Configuration Management Plan. This plan will help manage the software development activities and the installation of information into the TEXSYS knowledge base.

c. Software Assurance Plan. This plan will establish the mechanisms whereby software and knowledge base information is developed to assure conformance,as appropriate for expert systems, with established software requirements, approaches, and standards. Additional software standards appropriate for expert systems will be developed.

d. TEXSYS Verification and Validation Plan. This plan will define the specific approach to validation of the TEXSYS and verfication and validation of the supporting interfaces and utilities, for both the initial system and final system development stages. Included will be detailed descriptions of the various simulations required to verify TEXSYS and a matrix showing the correlation of verification simulations and verification tests. The source(s) for these simulations will also be identified.

These documents and the TEXSYS System Design Specification will be reviewed for approval at the Preliminary Design Review (PDR).

8.2.4 Initial System Development Stage.

The initial TEXSYS development activities will consist of procurement of test and demonstration hardware and software, and include two major phases of knowledge base development. The development activities at ARC will concentrate on development of TEXSYS knowledge bases and the human interface to TEXSYS, while JSC will take the lead in developing the software needed to interact with the real-time systems with which the TEXSYS will interface. A lead role for a Center does not preclude a participating role for the other Center.

Phase one of the knowledge base development will consist of the acquisition and organization of knowledge about the TCS Testbed components and topology, and the development of rules for detecting and diagnosing problems. During this phase a static knowledge base will be used for testing purposes.

Phase two will include the modification of the system to successfully accommodate real-time operation and the provision of simulated dynamic data to test this major enhancement. Full verification and validation of the Phase two TEXSYS will be accomplished per the TEXSYS V&V Plan.

Among the documents to be developed during this period are the following:

a. TEXSYS Training Plan. This plan will identify the training needs for the following development phases and demonstration activities.

b. Failure Modes and Effects Analysis. This analysis will identify single point TEXSYS hardware failures that can affect the conduct of the TCS Demonstration.

c. Interface Control Documents. These documents will finalize the TCS TEXSYS hardware and software interfaces with the TCS Testbed and DACS.

d. Operational Definition. This document will provide a preliminary definition of operational phase activities of the TCS Demonstration.

e. TEXSYS Software Reference Manual. This is a detailed description of the software internals and design as written. This document is intended to facilitate future enhancements and maintenance modifications.

A Critical Design Review (CDR) will be conducted to review the current status of the TEXSYS and of the supporting plans and documentation. The detailed configuration of the TTB for the demonstration will be formalized at this milestone. This review will precede a major shift in the development activities from prototype development to integration of TEXSYS in the TCS Testbed.

8.2.5 Final System Development.

After completion of the CDR and delivery, installation, and checkout of the TCS Demonstration software at JSC, the final development stage will begin. During this stage, the TEXSYS system will be completed and validated. The focus of development, integration and validation activities will be at the JSC facility; but with strong reliance on the technical cognizance of the Systems Autonomy Demonstration Project Office knowledge engineers for the demonstration system. Human interface development activities will be carried out at the ARC facility with continuing updates and integration as necessary at JSC, with periodic installation of necessary graphics interface software and knowledge base updates.

The system validation and integration activities at JSC shall be divided into three activities. First, the system that is delivered by ARC shall be tested using the Verification and Validation plan.

Next, the knowledge base of the expert system shall be expanded in conjunction with the ARC knowledge engineers (RIS), the domain experts (EC), and the integration experts (EF) to improve the knowledge representation, the domain expertise, and the operational competence of the expert system. In addition, when the final test and demonstration configuration of the TTB is selected, the expert system will have the knowledge base adapted to meet this configuration by joint efforts from the knowlege engineers and human factors personnel from ARC with the domain experts and integration experts at JSC.

Finally, the verification and validation tests shall be performed on the final demonstration TTB configuration jointly by ARC and JSC to insure that the expert system knowledge base is complete and correct. After passing these tests, TEXSYS shall be considered ready for the SADP 1988 demonstration phase.

In addition to the system development activities, any training specified in the TEXSYS Training Plan will be accomplished, the final V&V Plan and the TCS Demonstration Definition documents will be published, and the full verification and validation of the final TEXSYS integrated with the TTB will be accomplished per the relevant V&V plans and specifications.

This phase of the TEXSYS development will conclude with the TCS Operational Readiness Review (ORR). The ORR will examine all TMS Demonstration activities to determine the readiness of the system, the procedures and documentation, and the personnel for the conduct of the operational phase of the TCS Demonstration.

8.2.6 TCS Demonstration Stage.

After successful completion of the ORR, the final phase, the Demonstration Phase, will begin. This stage, conducted jointly by ARC and JSC, will include the demonstration operations, and the post demonstration analysis and review.

The operations stage will involve the actual conduct and documentation of the TEXSYS in managment and control of the TCS Testbed. The analysis and review phase will provide an integrated retrospective analysis of the system capabilities, and the development process, to provide insight into the effectiveness of the TEXSYS in management and control of the TCS Testbed and to identify improvements that can be made in later phases of the SADP project activities

A TCS Demonstration Review will be conducted to examine the results of the demonstration and the analysis and review phases. This review will complete the technical activities associated with the SADP TCS Demonstration in 1988.

8.3 Formal Reviews.

Formal project reviews will be conducted at appropriate points in the design and implementation of the TCS Demonstration. Five major reviews have been identified for the TCS Demonstration as follows, with their estimated schedule dates:

a. System Requirements Review (SRR-1/87).
b. Preliminary Design Review (PDR-4/87).
c. Critical Design Review (CDR-8/87).
d. Operational Readiness Review (ORR-7/88).
e. TCS Demonstration Review (TDR-10/88).

The reviews are considered major milestones for the conduct of the TCS Demonstration, and are shown in the TCS Demonstration Master Schedule. To ensure appropriate representation by NASA HQ personnel, the SADP Project Manager will give advance notification to the A&R Program Manager of the schedule and agenda of these reviews.

8.3.1 System Requirements Review.

The objective of the System Requirements Review (SRR) is to determine whether or not the scope and depth of system design requirements, the definition of the system design concept, and the understanding of the demonstration requirements, as identified in the TCS System Requirements Definition, are adequate to proceed with the design and procurement of the TEXSYS. The review will provide an in-depth critique of the system concept, system requirements, technical approach, cost estimates, and schedule estimates for the TCS demonstration. The scope of the SRR will be limited to the TCS Demonstration.

8.3.2 Preliminary Design Review.

The objective of the Preliminary Design Review (PDR) will be to determine whether or not the system, as designed, meets the overall functional and performance requirements identified in the TEXSYS Systems Requirements Definition. The PDR will be an in-depth review and assessment of the preliminary design and will address completeness, balance between requirements and capabilities, and technical risk of the design. Safety, SW assurance, and configuration management plans will be reviewed during the PDR. The overall design and supporting documentation of the TEXSYS system will be critiqued to discover design errors, weaknesses, or risks, and to assure that the TCS Demonstration can be accomplished within schedule and budget constraints.

8.3.3 Critical Design Review.

The objective of the Critical Design Review (CDR) is to determine the completeness of the prototype system detailed design; detailed design and development specifications, schedules, and budgets; documentation plans; and test plans. The CDR will include an evaluation of functional completeness of the TEXSYS design, an analysis of the expected TEXSYS performance and of the suitability of this performance in the TCS demonstration, and a review of interface specifications, design reliability and maintainability, and demonstration safety plans and implementation standards. TTB test configuration for the demonstration will be formalized. Plans for integration of the prototype technology into the TCS testbed system will be reviewed. Successful completion of the CDR establishes the design of the TEXSYS system.

8.3.4 Operational Readiness Review.

The purpose of the Operational Readiness Review (ORR) will be to assess the readiness of the TEXSYS system, the demonstration, operations and maintenance procedures and documentation, and demonstration personnel for conduct of the TCS demonstration.

8.3.5 TCS Demonstration Review.

The purpose of the TCS Demonstration Review (TDR) is to assess the overall applicability of the AI technologies used in the TCS demonstration for use on the Space Station and other NASA programs. The TDR will examine the performance of the TCS Expert System in the TCS Demonstration and determine the strengths and weaknesses of the technologies demonstrated. The review will identify the options and opportunities for extending the TCS Expert System for future demonstrations or operational use. It will also provide a review of the process by which the TCS demonstration was developed, for use in planning follow-on SADP activities. The results and findings of the TDR will be documented for use by the SADP Office and by others.

8.4 Configuration Management.

The SADP Project configuration management strategy is to provide the necessary administrative and technical controls for effective implementation of design, development, integration, and test policies as put forth by the SADP Office. A key part of this strategy is the Configuration Management Plan which will develop and define the procedures for providing appropriate levels of configuration identification and accounting to ensure an orderly and traceable development process for software and hardware. This plan will establish the project configuration management requirements and detail administrative procedures to be used to assure that all project hardware, software, facilities, documentation, and schedules conform to established baseline documentation.

8.5 Controlled Items.

The Associate Administrator, Office of Aeronautics and Space Technology, will control any changes in the following items:

a. The TCS Demonstration Project Plan.
b. Changes in the overall project funding.
c. Major changes in authorized scope of work.
d. Major changes in the CDR and TCS Demonstration milestones.

8.5.1 Resources Management.

A Resource Management Plan will be developed that establishes the specific approach, policies, and procedures for management, control, and reporting of all SADP financial resources. This plan will describe the mechanisms used for projecting, tracking, and controlling project costs; and for evaluating and reporting financial information. The resources management system will be based upon the NASA Managment Information and Control System (MICS) described in NHB 2340.2, and will be organized around the SADP Project Work Breakdown Structure.

8.6 Work Breakdown Structure.

A detailed Work Breakdown Structure (WBS) will be developed for the TCS Demonstration and integrated into the SADP Work Breakdown Structure. Additional elements may be added to the TCS WBS, and lower levels will be developed to provide adequate visibility and management of the work performed under this project. The detailed TCS Work Breakdown Structure is described in the TCS Work Breakdown Structure document, and is organized in the Level 3 (Project) Work Breakdown Structure for the Systems Autonomy Demonstration Project as follows:

TCS Work Breakdown Organization

1. Project Management.
2. 88 Demonstration.
   - 2.1 System Engineeering.
   - 2.2 HW & SW procurements.
   - 2.3 Developed Software.
   - 2.4 System Integration.
   - 2.5 Operations.
3. 90 Demonstration.
4. 93 Demonstration.
5. 96 Demonstration.
6. Facilities and Support.

8.7 Work Breakdown Schedule.

The TCS Demonstration is part of the SADP. A schedule for the completion of the SADP, including the TCS Demonstration, is shown below in figure 7. This schedule is organized within the framework of the Work Breadown Structure described above.

The TCS Work Breakdown schedule is shown below in figure 8.

8.8 Schedule Maintenance and Reporting.

The SADP Master Schedule and the TCS Demonstration schedule will be reported in the monthly Project Management Report. Schedule accomplishments and variances will be reported graphically following the format in NHB 2340.2. Brief explanatory notes will be added to the charts as needed for visibility.

In the event that changes in baseline schedules or major milestones become necessary, new schedules will be defined and the revised baseline schedule will be identified by month and year. All changes in project milestones will be approved by the SADP Manager and coordinated with the JSC Team Leader and the TTB Project Manager. In addition, changes in controlled items will be approved by NASA headquarters.

SYSTEMS AUTONOMY DEMONSTRATION PROJECT
MASTER SCHEDULE

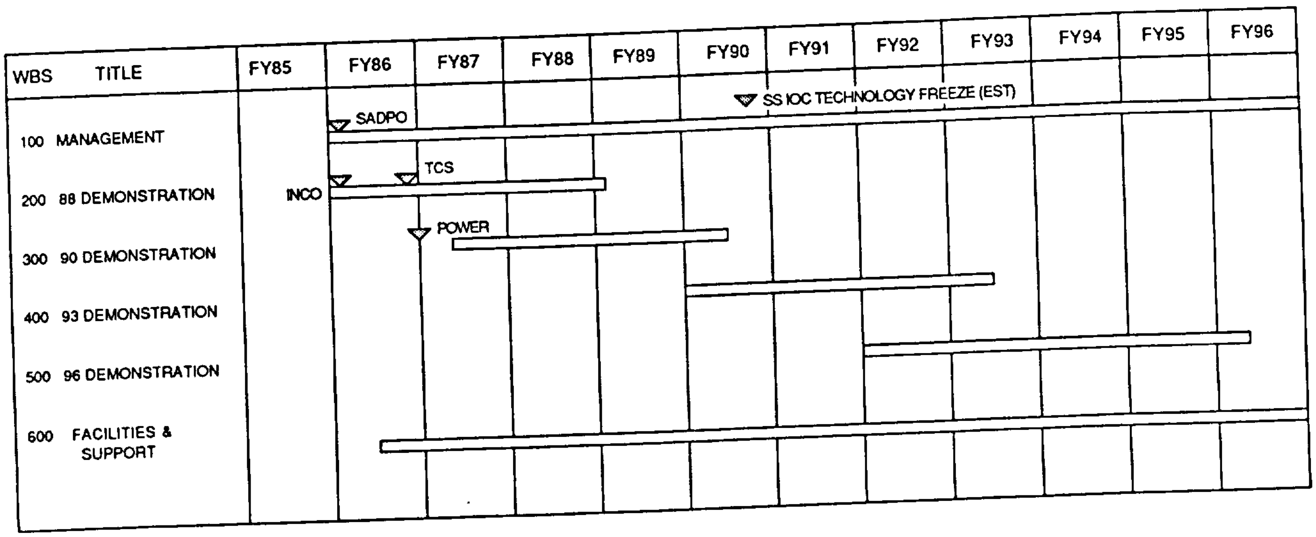

Figure 7. SADP Work Breakdown Schedule.

SADP 88 DEMONSTRATION SCHEDULE
TCS EXPERT SYSTEM

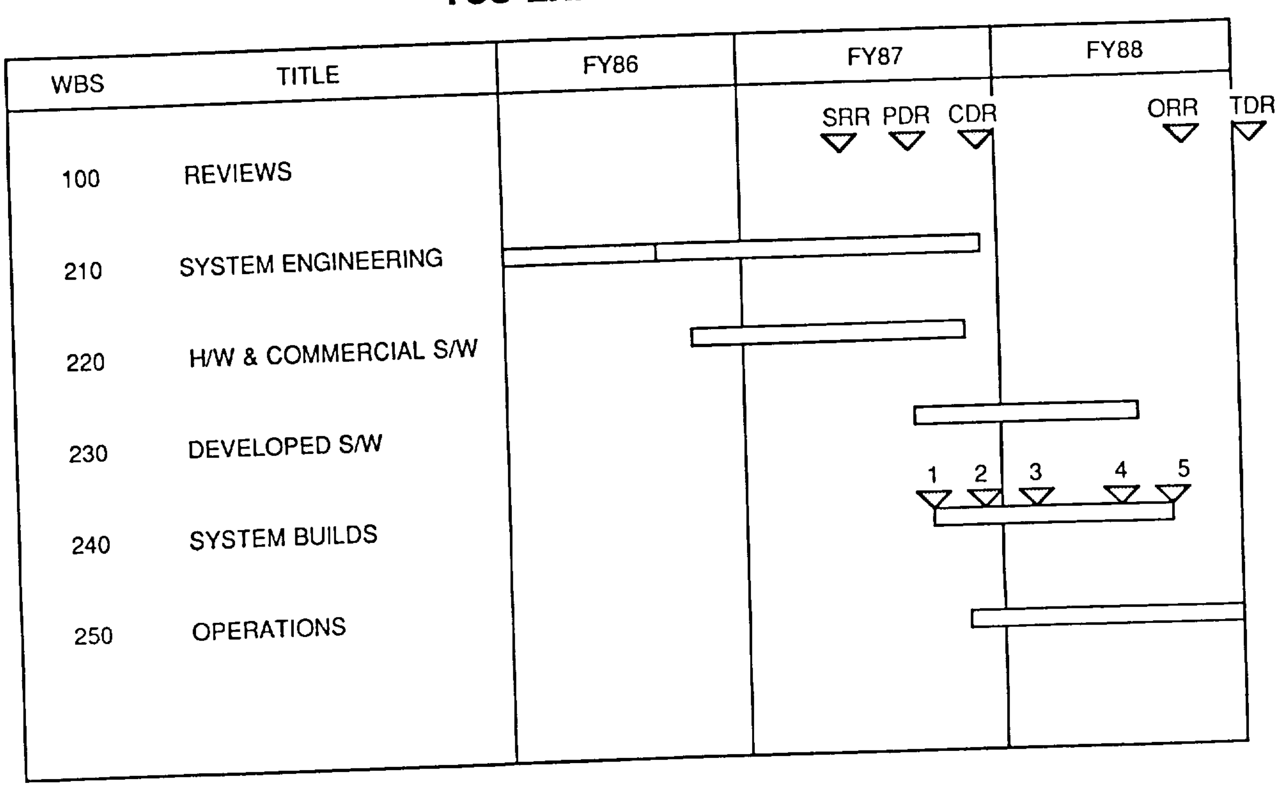

Figure 8. TCS Work Breakdown Schedule.

8.9 Data Management.

Guidelines will be established by the SADP Manager to provide administrative and procedural direction for the systematic identification, definition, control, coordination, documentation, distribution, and storage of all TCS Demonstration data. These guidelines will use the NASA DATA Requirements List/Data Requirements Definition (DRL/DRD) approach to establish data requirements.

CHAPTER 9

MANAGEMENT PLAN

The Management Plan for the Systems Autonomy Demonstration Project (SADP) defines the project organization and responsibilities for the SADP, including the Thermal Control System Demonstration.

9.1 Management Approach

9.1.1 NASA Headquarters.

The Associate Administrator of Aeronautics and Space Technology (OAST) is responsible for overall direction, funding, and evaluation of the System Autonomy Demonstration Project. Headquarters responsibility for this function has been assigned to the Information Sciences and Human Factors Division (RC), within which the Automation and Robotics Program Office has direct responsibility for accomplishment of this role.

9.1.2 Ames Research Center (ARC).

Ames Research Center has overall responsibility for the development and implementation of the Systems Autonomy Demonstration Project. Within ARC, the responsibility for this project has been delegated to the Systems Autonomy Demonstration Project Office, an element of the Information Sciences Office (RI). ARC will work jointly with elements of the Johnson Space Center to carry out the Thermal Control System Project demonstration. Beside overall project management, ARC is specifically responsible for knowledge base and human interface development of the Thermal Control Expert System (TEXSYS).

9.1.3 Johnson Space Center (JSC).

Johnson Space Center has responsibility for development and testing of the Space Station Thermal Control System Testbed. Working jointly with ARC, JSC is responsible for developing and integrating the Thermal Control Expert System (TEXSYS) hardware and software systems into the TCS Testbed for demonstration.

9.1.4 Systems Autonomy Inter-Center Working Group (ICWG).

An Inter-Center Working Group has been established to review the SADP plans and progress, and to provide advice from an Agency viewpoint. The ICWG is chaired by Dr. Henry Lum, Chief of the ARC Information Sciences Office.

9.1.5 Automation and Robotics Management Committee.

An Automation and Robotics Management Committee has been established to review the SADP plans within the context of the NASA Automation and Robotics Program. This committee is chaired by Lee Holcomb, Director, Information Sciences and Human Factors Division at NASA Headquarters.

9.2 Organization.

9.2.1 SADP Project Office.

The Systems Autonomy Demonstration Project Office is structured as shown in figure 9 to manage the TCS and following demonstrations. The SADP Manager resides within the Information Sciences Office at ARC and has full responsibility for accomplishment of the goals of the SADP, including the TCS demonstration. The Project Manager, assisted by the Project Scientist, will coordinate the work planned and conducted by the ARC and JSC team leaders. The TCS 1988 Demonstration organization is shown in figure 10.

9.2.2 ARC TCS Demonstration Matrixed Personnel.

The ARC TCS demonstration effort involves the coordination of work performed by personnel matrixed or detailed to the SADP Office, by matrixed personnel from elsewhere in the Information Sciences Office, and by matrixed personnel from the Aerospace Human Factors Research Division (FL).

9.2.3 JSC TCS Demonstration Personnel.

The JSC TCS demonstration effort involves the coordination of work performed by personnel in the Crew and Thermal Systems Division (EC), the Systems Development and Simulation Division (EF), and the Mission Operations Directorate (DA3).

9.2.4 Project Research and Technology Support.

Project research and technology development support will be provided by the Artificial Intelligence Research and Applications Branch (RIA), the Intelligent Systems Technology Branch (RII), and the Human Machine Interactions Group of the Aerospace Human Factors Research Division (FL) at the Ames Research Center. Technology development support and integration support will also be provided by the Systems Development and Simulation Division at JSC. Project domain expert knowledge will be provided by the Crew and Thermal Systems Division (EC) at Johnson Space Center. Operational consultation will be provided by the Mission Operations Direactorate (DA3) at JSC.

9.2.5 ARC Project Support.

Procurement support will be provided by the ARC Contract Management Branch for Aerophysics (ASR), and facilities support will be provided by the Facilities Engineering Branch (EEF).

SYSTEMS AUTONOMY DEMONSTRATION PROJECT ORGANIZATIONAL STRUCTURE

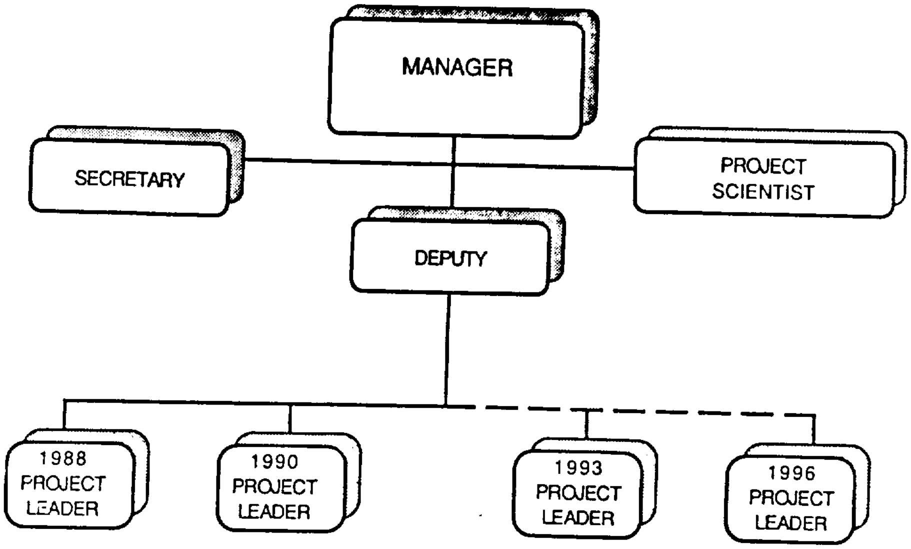

Figure 9. SADP Organization.

TCS DEMONSTRATION ORGANIZATION

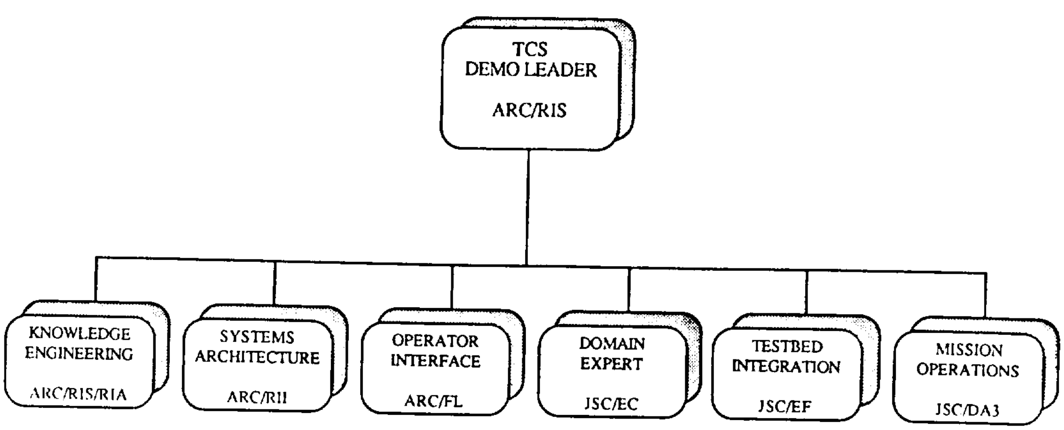

Figure 10. TCS Demonstration Organization.

9.2.6 JSC Project Demonstration Support.

Project support at JSC will be provided by the Crew and Thermal Systems Division (EC), the Systems Development and Simulation Division, and the Mission Operations Directorate (DA3). Activities include the provision of the TTB (EC), knowledge engineering and expert system development support (EF) in conjunction with ARC RIS, domain expertise (EC), mission operations consultation (DA3), integration of TEXSYS into the TTB (EF), test and validation of the integrated system (EC and EF), organization of the demonstrations (EC and EF), and liason with the Space Station Project Office at JSC.

9.3 Management Responsibilities.

Specific responsibilities of the TMS demonstration management team are defined below.

9.3.1 SADP Project Manager.

The SADP Manager is responsible for the definition and execution of all elements of the SADP, including the TCS demonstration. In particular, the SADP Manager is responsible for SADP project planning, scheduling, budget management, and reporting to NASA HQ. The SADP PM reports to the Chief of the Information Sciences Office at ARC and to the Automation and Robotics Program Manager at OAST.

9.3.2 SADP Deputy Project Manager.

The SADP Deputy Project Manager (Deputy PM) shares the responsibility for overall management of the SADP and acts for the Project Manager in his/her absence. In addition, the Deputy PM will serve as the Project Safety Officer and prepare the Project Safety Plan. The Deputy PM will also serve as the Project Assurance Officer. The Deputy PM is responsible for day-to-day monitoring of project status, and is responsible for ensuring that facilities are available to meet the needs of the SADP. The Deputy PM is responsible for and supervises office administrative operations, program control, and procurements.

9.3.3 SADP Project Scientist.

The Project Scientist reports to the SADP PM and is responsible for advising the PM on appropriate technologies and technical approaches to be followed in development of the TCS demonstration. The Project Scientist reviews the technical status of the project activities and identifies areas where additional engineering research or investigation is needed to identify appropriate technical approaches, and provides information on backup or alternate approaches, when requested.

9.3.4 ARC TCS Demonstration Team Leader.

The ARC TCS Demonstration Team Leader reports to the SADP Manager and is responsible for coordination and accomplishment of technical activities assigned to ARC within preestablished schedule and financial constraints, and for integration of these activities with those being carried out at JSC.

9.3.5 JSC TCS Demonstration Team Leader.

The JSC TCS Demonstration Team Leader coordinates with the SADP Project Manager and reports to the Chief of the Systems Development and Simulation Division at JSC. The JSC TCS Demonstration Team Leader is responsible for coordination of all technical activities assigned to JSC, within pre-established schedule and financial constraints, and for integration of these activities with those being carried out at ARC.

9.3.6 JSC TCS Lead Domain Expert.

The JSC TCS Lead Domain Expert interfaces with the JSC TCS Demonstration Team Leader and coordinates with the SADP Manager, and reports to the Chief of the Crew and Thermal Systems Division at JSC. He is responsible for providing the domain expertise and, with the JSC TCS Demonstration Team Leader, for conducting the integration testing, validation, and demonstration of the TEXSYS at JSC.

9.3.7 JSC TCS Mission Operations Expert.

The JSC TCS Mission Operations Expert interfaces with the JSC TCS Demonstration Team Leader and coordinates with the SADP Manager, and reports to the Chief of the Facility and Support Systems Division at JSC. He is responsible for providing consultation and advice on recent trends and technology advancements in operations' automation, and the application of those technologies and current mission operations' philosophy to the TCS.

9.4 Formal Agreements.

Formal agreements, including Memoranda of Understanding, Memoranda of Agreement, plans, or other appropriate documents; will be established between ARC and JSC and between the SADP Project Office and other organizations as necessary for the accomplishment of the SADP TCS Demonstration. The following documents have been identified as required formal agreements.

9.4.1 Memorandum of Understanding of May 1986.

a. Signatories.

ARC: W. Ballhaus, Director, Ames Research Center
V. Peterson, Director of Aerophysics
H. Lum, Chief, Information Sciences Office.

JSC: J. Moore, Director, Johnson Space Center.
A. Cohen, Director of Research and Engineering.
M. Engert, Deputy Director for Engineering.
P. Kurten, Chief, Sim. and Av. Integ. Division.

b. Purpose.

Develop and maintain a relationship between ARC and JSC facilitate the development of applications and research in Artificial Intelligence (AI).

9.4.2 TCS Demonstration Project Plan.

a. Signatories.

ARC: V. Peterson, Director of Aerophysics.
T. Snyder, Director of Aerospace.
H. Lum, Chief, Information Sciences Office.
D. Nagel, Chief, Aerospace Human Factors Division
C. Wong, Manager, SADP
P. Friedland, Project Scientist, SADP

JSC: H. Pohl, Director of Engineering.
P. Kurten, Chief, Sys. Dev. and Sim. Division.
W. Guy, Chief, Crew and Thermal Systems Division.
K. Russell, Chief, Facility and Support Sys. Div.

HQ: L. Holcomb, Director, Information Sciences and Human Factors Division.

b. Purpose.

Describes the overall plan for carrying out the Systems Autonomy Demonstration of the Thermal Control System for Space Station.

9.4.3 TCS Demonstration Organizational Responsibilities.

a. Signatories.

ARC: H. Lum, Chief, Information Sciences Office.
D. Nagel, Chief, Aerospace Human Factors Division.
C. Wong, Manager, SADP

JSC: P. Kurten, Chief, Sys. Dev. and Sim. Division.
W. Guy, Chief, Crew and Thermal Sys. Division.
K. Russell, Chief, Facility and Support Sys. Div.

b. Purpose.

Defines in detail the responsibilities and committments of the ARC and JSC organizations involved, including descriptions of lead and support roles and specific deliverables for each organization.

9.5 Formal Development Reviews.

The following formal project development reviews will be conducted at appropriate points in the design and implementation of the TCS Demonstration. See Section 8.3 for detailed descriptions of each.

a. System Requirements Review (SRR).
b. Preliminary Design Review (PDR).
c. Critical Design Review (CDR).
d. Operational Readiness Review (ORR).
e. TMS Demonstration Review (TDR).

9.6 Status Reviews.

Periodic status reviews will be conducted by the SADP Manager to ensure communications among the various organizations and individuals associated with the SADP project. In addition, electronic mail services, such as Telemail, and other electronic means of communications, such as the NASA Video Conferencing System, will be used to maintain formal and informal communications. The SADP Manager will provide oral briefings to ARC management and to OAST on a periodic basis or as requested.

In addition to these reviews, presentations will be made to NASA HQ, the Automation and Robotics Advisory Committee, and the SADP Inter-Center Working Group as deemed appropriate by these organizations and the Chief of the Information Sciences Office.

9.7 Status Reports.

The SADP Manager will maintain personal, telephonic, and Telemail contact with the A&R Program Manager and with ARC management. A monthly Project Management Report will be prepared covering technical and financial status, progress, and problems. This report will be based upon the standard OSSA/OAST Project Management Information and Control System format, NHB 2340.2. It will be provided by the SADP to ARC and JSC management and to OAST the following month.

Each contractor will be required to present formal progress reports at the contractor's site or at ARC on a regularly scheduled basis. These reports will cover technical progress, problems, further events, schedules, and resources. Technical direction and/or contractual direction will be given to assure timely prosecution of the contracted efforts. Financial management reports shall be submitted monthly by the contractor on NASA form 533P as required by NHB 9501.2A. Contents of these reports will be consistent with the contractor's accounting system and will cover direct labor, material, travel, equipment, other direct costs, and General and Administrative expenses.

CHAPTER 10

PROCUREMENT PLAN

This chapter describes the procurement plan approach. The procurements and contracts planned for the TCS demonstration are of three types: procurements of hardware and software to be used in the demonstration; procurement of facilities to support SADP; and procurement of contract support, primarily programming support service.

The major hardware and software needed to support the actual demonstration, together with test equipment and other equipment needed to develop the demonstration will be procured through standard NASA procurement methods.

Some minor hardware and software will be procured at ARC and JSC through competitive procurements. When necessary to maintain compatibility with existing equipment or to minimize maintenance costs, some sole source (make and model) procurements may be used.

Contract support for this demonstration, both at ARC and at JSC, will be provided through existing support service contracts.

CHAPTER 11

SAFETY PLAN

The SADP PM is responsible for overall SADP safety, including safety of the TCS demonstration. The PM will be responsible for the safety of personnel and equipment under his/her control per the applicable elements of NMI-1700, NASA Basic Safety Requirements. Safety of the TMS Demonstration Project during and after hardware/software integration into the TTB DACS (including personnel certification) is the responsibility of the JSC/TTB Project Manager. All safety related activities must therefore also comply with all applicable elements of JSCM 1700D, "Johnson Space Center Safety Manual", and must be coordinated with the TTB Project Manager.

11.1 Safety Plan.

The Deputy PM will be the Project Safety Officer (PSO) responsible for developing and implementing the Project Safety Plan. This plan will be coordinated with the appropriate technical and safety organizations at ARC and JSC.

The Safety Plan will be integrated by the Project Safety Officer to include major contractor safety plans. The Project Safety Officer will review, and approve for compliance and implementation, those plans and activities to ensure compliance with the Project Safety Plan.

11.2 Hazards Analysis.

To ensure the safe accomplishment of the TCS Demonstration, an FMEA and Hazards Analysis will be conducted to identify potentially hazardous failure modes. This analysis will be used in the development of the design of TEXSYS, to eliminate to the maximum degree feasible all failure modes that pose hazards to personnel; and to eliminate or minimize failure modes that pose hazards to equipment, the Thermal Control System testbed, or the TCS Demonstration.

CHAPTER 12

RELIABILITY AND QUALITY ASSURANCE

The primary purpose of the Reliability and Quality Assurance (R&QA) function will be to provide a coordinated, overall assessment of the results and risks associated with the TCS Demonstration to maximize project success at acceptable costs. The TCS Demonstration Project will utilize appropriate provisions from NASA Standards to establish reliability and quality assurance actions tailored to acceptable costs and risks.

The Project Assurance Manager will assure that the system specifications include the required provisions for reliability and quality assurance.

12.1 <u>Reliability</u>.

The project strategy will include thorough analysis of the needs for and provisions for redundancy and modularity to meet the reliability and operability standards of the TCS Demonstration Project. The Project Assurance Manager will track Reliability progress and status.

12.1.1 Failure Modes and Effects Analysis (FMEA).

An FMEA will be conducted to identify single point hardware failures to ensure appropriate hardware redundancy is provided in the system design.

12.2 <u>Quality Assurance</u>.

The project strategy will be to independently measure and assess the extent and effectiveness of meeting system requirements, and to raise an alarm in the event of actual or probable shortfalls. This will include monitoring existing standards, procedures and tests, and recommend changes where necessary. All TTB integration activities at JSC will comply with existing quality engineering and quality assurance systems in effect at JSC.

12.2.1 Software Assurance.

a. Risk Classification. The TMS Demonstration is subject to the requirements of NMI 2410.6, "NASA Software Management Requirements for Flight Projects"; and AMM 5333-2, "Software Assurance". The TCS demonstration is considered a Class B (Moderate Risk) project for the purposes established in AMM 5333-2.

b. Software Assurance Plan. A Software Assurance Plan will be prepared in accordance with AHB 5333-1, "Requirements for Establishment of Software Assurance Programs". This plan will cover all Software Assurance (SWA) activities to be accomplished for the TMS Demonstration. The plan will identify all items of TCS Demonstration software that are subject to SWA control.

For the purposes of this plan, the term "software" will include databases, knowledge bases, interface code, and other information stored in the computers that are used in the development or demonstration of the TCS Expert System.

CHAPTER 13

FUNDING/MANPOWER SCHEDULE

13.1 Budget/Manpower by Organization.

Table 5. 1988 TCS Demonstration Budget By Organization ($K)

		FY87	FY88	FY89
Knowledge Engineering	(ARC RIA)	100		
o AI HW/SW Equipment		95		
o AI Applied Research Studies		0		
o Analysis/Reporting		195		
System Architecture	(ARC RII)	40		
o Hardware		30		
o Software		70		
Operator Interface	(ARC FL)	150		
o AI Computer		100		
o AI Software		70		
o Programming Support		0		
o Analysis/Reporting		320		
Demo Facilities/Tools	(ARC RIS)	350		
o Management Reserve		700		
o Computer HW		160		
o Documentation/Clerical/Graphics Support		100		
o Engineering Support		25		
o Process Control Consulting		70		
o Safety/RQ&A		300		
o Laboratory/Office Spaces		50		
o Validation Hardware		50		
o Validation Software		0		
o Analysis/Reporting		1805		
Thermal Testbed	(JSC EC)	100		
o DACS Software Integration		160		
o Contractor Support		0		
o Analysis/Reporting		260		
TTB Integration	(JSC EF)	100		
o Hardware Interfaces		240		
o Contractor Support		340		
Mission Operations	(JSC DA3)	0		
Totals		2990	2175	445

Table 6. 1988 TCS Demonstration Manpower (Civil Service/Contract)

		FY87	FY88	FY89
Knowledge Engineering	(ARC RIA)	0.5/0.0		
System Architecture	(ARC RII)	0.5/0.0		
Operator Interface	(ARC FL)	1.5/1.0		
Demo Facilities/Tools	(ARC RIS)	3.5/3.5		
Thermal Testbed	(JSC EC)	0.5/2.0		
TTB Integration	(JSC EF)	1.5/3.0		
Mission Operations	(JSC DA3)	0.5/0.0		
		8.5/9.5	9.0/9.5	4.0/1.0

Table 7. 1990 Demonstration Budget By Organization ($K)

		FY87	FY88	FY89
Knowledge Engineering	(ARC RIA)			
o University Grants		100		
o AI Basic Research Studies		80		
		180		
System Architecture	(ARC RII)			
o HW/SW Integration		0		
		0		
Operator Inter. Res.	(ARC FL)			
o University Grants		65		
o Programming Support		35		
		100		
Demo Facilities/Tools	(ARC RIS)			
o Management Reserve		0		
o HW Development Equipment		50		
o SW Development Tools		50		
o AI Applied Research Studies		100		
		200		
Testbed	(JSC EC)			
o Software Integration		0		
o Contractor Support		0		
		0		
Testbed Integration	(JSC EF)			
o Hardware Interface		0		
o Contractor Support		0		
		0		
Mission Operations	(JSC DA3)	0		
Totals		480	1410	3210

Table 8. 1990 Demonstration Manpower (Civil Service/Contract)

		FY87	FY88	FY89
Knowledge Engineering	(ARC RIA)	0.5/0.0		
System Architecture	(ARC RII)	0.0/0.0		
Operator Interface	(ARC FL)	0.5/0.5		
SADP Management	(ARC RIS)	0.5/0.0		
Testbed	(JSC EC)	0.0/0.0		
Testbed Integration	(JSC EF)	0.0/0.0		
Mission Operations	(JSC DA3)	0.0/0.0		
		1.5/0.5	2.5/0.0	8.0/8.5

Table 9. SADP Budget/Manpower Summary by Organization

		FY87	FY88	FY89
BUDGET ($K)				
1989 TCS Demo.				
Knowledge Engineering	(ARC RIA)	195		
System Architecture	(ARC RII)	70		
Operator Interface	(ARC FL)	320		
Demo Facilities/Tools	(ARC RIS)	1805		
Thermal Testbed	(JSC EC)	260		
TTB Integration	(JSC EF)	340		
Mission Operations	(JSC DA3)	0		
		2990	2175	445
1990 Demo.				
Knowledge Engineering	(ARC RIA)	180		
System Architecture	(ARC RII)	0		
Operator Interface	(ARC FL)	100		
Demo Facilities/Tools	(ARC RIS)	200		
Testbed	(JSC EC)	0		
Testbed Integration	(JSC EF)	0		
Mission Operations	(JSC DA3)	0		
		480	1410	3040

SADP Budget Summary ($K)		FY87	FY88	FY89
Knowledge Engineering	(ARC RIA)	375		
System Architecture	(ARC RII)	70		
Operator Interface	(ARC FL)	420		
SADP Facilities/Tools	(ARC RIS)	2005		
Subsystem Testbeds	(JSC EC)	260		
Testbed Integration	(JSC EF)	340		
Mission Operations	(JSC DA3)	0		
		3470	3585	3630

SADP MANPOWER (CIVIL SERVICE/CONTRACT)

		FY87	FY88	FY89
Knowledge Engineering	(ARC RIA)	1.0/0.0		
System Architecture	(ARC RII)	0.5/0.0		
Operator Interface	(ARC FL)	2.0/1.5		
SADP Management	(ARC RIS)	4.0/3.5		
Testbed	(JSC EC)	1.0/2.0		
Testbed Integration	(JSC EF)	1.0/3.0		
Mission Operations	(JSC DA3)	0.5/0.0		
		10.0/10.0	11.5/10.5	12.0/11.0

11.5/9.5 12.0/9.5

13.2 Work Breakdown Budget.

Table 10. Work Breakdown Budget Level 3 Summary.

WBS	Work Element	FY 87	88	89
1.0	Project Management	540	550	560
2.0	1988 Demonstration - TCS	1370	1505	145
3.0	1990 Demonstration	490	830	2200
4.0	1993 Demonstration	0	300	350
5.0	1996 Demonstration	0	0	0
6.0	Facilities and Support	1070	400	400
		3470	3585	3655

Table 11. Work Breakdown Budget Level 4 Summary.

1.0	Project Management	540	550	560
2.0	1988 Demonstration - TCS	1370	1505	145
	2.1 System Engineering	260		
	2.2 HW & SW Procurements	610		
	2.3 Developed SW	400		
	2.4 System Integration	100		
	2.5 Operations	0		
3.0	1990 Demonstration	490	830	2200
	3.1 Systems Engineering	440		
	3.2 HW & SW Procurements	50		
	3.3 Developed SW	0		
	3.4 System Integration	0		
	3.5 Operations	0		
4.0	1993 Demonstration	0	300	350
5.0	1996 Demonstration	0	0	0
6.0	Facilities and Support	1070		
		3470	3585	3655

Table 12. Work Breakdown Buoget Level 5 Summary.

WBS	Work Element	Organization	FY87	FY88	FY89
1.0	Project Management	ARC RIS	540	550	560
	Management Reserves	ARC RIS	350		
	Safety RQ&A	ARC RIS	30		
	Documentation, Clerical	ARC RIS	160		
2.0	1988 Demonstration - TCS		1370	1505	145
2.1	Systems Engineering		260	150	145
	AI Applied Research Studies	ARC RIA	100		
	Analysis and Reporting		0		
	Safety RQ&A	ARC RIS	40		
	Contractor Support	JSC EC	40		
	Contractor Support	JSC EF	80		
2.2	HW & SW Procurements		610	645	0
	AI HW & SW Equipment	ARC RIA	100		
	System Arch HW	ARC RII	40		
	System Arch SW	ARC RII	30		
	HI AI Computer	ARC FL	150		
	HI AI Software	ARC FL	30		
	Validation HW	ARC RIS	50		
	Validation SW	ARC RIS	50		
	Performance Upgrades	ARC RIS	0		
	TTB HW Interfaces	JSC EC	100		
	TTB Integration HW/SW	JSC EF	80		
2.3	Developed SW		400	220	0
	Programming Support	ARC RIS	80		
	Engineering Support	ARC FL	100		
	Contractor Support	JSC EC	140		
	Contractor Support	JSC EF	80		
2.4	System Integration		100	300	0
	Programming Support	ARC FL	0		
	DACs SW Integration	JSC EF	100		
	Contractor Support	JSC EC	0		
	Contractor Support	JSC EF	0		
2.5	Operations		0	190	0
	Contractor Support	JSC EC	0		
	Safety/RQ&A	ARC RIS	0		
3.0	1990 Demonstration		490	830	2200
4.0	1993 Demonstration		0	300	350
5.0	1996 Demonstration		0	0	0
6.0	Facilities and Support		1070	400	400
	Computer HW		770		
	Laboratory/Office Spaces		300		
			3470	3585	3655

CHAPTER 14

FACILITIES

14.1 ARC Development Facilities.

Extensive computer support will be required to support the system engineering and software development activities that will occur at ARC. Two sets of development facilities will be required. The first set includes a Symbolics 3670 computer and color display to be located in building 239 and connected via (TBD) to the ARC LAN. This set will be used by the Human Factors Research Division (Code FL) to develop the human interface to the TEXSYS system. This equipment does not currently exist at ARC and will be procured under the SADP aegis.

The second set of development facilities will be located in building 244. This will consist of a network of computers which includes the Symbolics 3670, a Symbolics 3620, a MicroVax II, and a VAX 11/780 (later to be upgraded to a VAX 8800).

The KEE 3 knowledge engineering development environment will be installed on all three Symbolics machines used to support the TCS Demonstration.

All of the RI systems noted above will be connected together by an Ethernet LAN using TCP/IP protocols. The VAX will provide file transfer access to the FL Symbolics system over the ARC LAN.

To provide project management support, personal computers or computer terminals will be provided for all SADP Project Office personnel, together with communications access to the ISO support computer (currently a VAX 11/780).

The SADP 88 Demonstration team will have sole and exclusive use of the Symbolics 3670 and MicroVAX II beginning in January 1987, and extending until the completion of the project, or until the SADP Manager determines that exclusive use is no longer needed. If the exclusive access to the MicroVAX II has an unacceptable impact on other priority projects, in the judgment of the ISO Chief, then the SADP Project Office will provide funding for the procurement of a second MicroVAX II system.

In addition, this team will have top priority use of the Symbolics 3620 during this same period.

14.2 JSC TCS Development Facilities.

The primary JSC development facility will be a Symbolics 3655 (in building 32) with a full complement of disk and memory and a black and white monitor. This computer shall host software identical to that used at ARC (e.g., KEE 3.0) and will be upgraded as required to "match" the development computer at ARC.

A secondary JSC TCS development facility will be the AI lab (in building 17) which includes multiple Symbolics computers in the 3600 family and copies of KEE 3.0.

CHAPTER 15

DOCUMENTATION PLAN

An SADP Documentation Plan will be developed that identifies all SADP Controlled documents. This plan will establish the purposes, inter-relationships, and orders of precedence among these documents; and will establish a standard format for these documents.

For the SADP Project, the designation "Controlled Document" refers to a document that is maintained under the policies and procedures set up in the Documentation Plan and which is modified only with the approval of the SADP PM. A distribution list will be prepared and maintained for each controlled document to ensure that revisions and updates are distributed to each document recipient.

The documents noted below have been identified as needed for the successful execution of the TMS Demonstration Project. As the TMS Demonstration is further defined, the Project Documentation Plan will be revised to reflect changes and additions to this list.

15.1 TCS Demonstration Documents.

a. TCS Demonstration Project Plan.
b. TEXSYS System Requirements Document.
c. TCS Demonstration Interface Control Documents.
d. Configuration Management Plan.
e. Safety Plan.
f. Hazards Analysis.
g. Failure Modes and Effects Analysis.
h. Software Assurance Plan.
i. TCS Demonstration Test Plan.
j. TCS Demonstration Review.
k. SADP Documentation Plan.
l. TEXSYS System Design Specification.
m. TEXSYS Verification and Validation Plan.
n. TEXSYS Training Plan.
o. Operational Definition.
p. TCS Demonstration Definition.
q. Project Management Reports.
r. Operator Interface Functional Requirements.
s. Operator Interface Software Development Specifications.
t. TEXSYS Software Reference Manual.

CHAPTER 16

GLOSSARY

ARC	Ames Research Center.
DA	JSC Mission Operations Directorate.
DACS	Data Acquisition and Control System.
DARPA	Defense Advanced Research Projects Agency.
DMS	Data Management System.
EC	JSC Crew and Thermal and Thermal Systems Division.
EF	JSC Simulation and Avionics Integration Division.
FL	ARC Aerospace Human Factors Research Division.
JPL	Jet Propulsion Lab.
JSC	Johnson Space Center.
NASA	National Aeronautics and Space Administration.
OAST	Office of Aeronuatics and Space Technology.
R	Associate Administrator for OAST.
RC	OAST Information Sciences and Human Factors Division.
RI	ARC Information Sciences Office.
RIA	ARC AI Research Branch.
RII	ARC Intelligent Systems Technology Branch.
RIS	ARC Systems Autonomy Demonstration Project Office.
RX	Stanford Expert System Program for Medical Diagnosis.
SADP	Systems Autonomy Demonstration Project.
TCS	Thermal Control System.
TEXSYS	Thermal Control System Expert System.
TTB	Thermal Testbed.